The **President** then introduced **Mr. T. H. Shields (M.)** who read his Paper entitled " The Giffard Centenary—A Survey of Locomotive Injector Development," which was afterwards discussed.

A vote of thanks to the Author, proposed by Colonel Harold Rudgard, O.B.E., was carried with acclamation.

THE GIFFARD CENTENARY.

A SURVEY OF LOCOMOTIVE INJECTOR DEVELOPMENT

Paper read before the Institution by T. H. SHIELDS (M.) in London on 25th October 1950.*

Repeated in Darlington on 1st November 1950 (page 666) and in Glasgow on 17th January 1951 (page 669)

PAPER No. 498

SYNOPSIS

The following Paper represents a historical survey of the development of locomotive injectors. From the theoretical work of Bernoulli and Venturi it is shown how the steam jet pump or injector was developed by (among others) D'Ectot, Bourdon and especially by Giffard. The process of mechanical improvement culminating in the present day injector is traced from these early models.

INTRODUCTION

Probably no other detail on the locomotive has been the subject of so many patents as the injector during the latter half of last century. To keep the Paper within rational limits only representative types of injectors have been included. Although the Giffard injector was not patented till 1858, it was in 1850 that the French engineer and scientist, Henri Jacques Giffard, first made known his theory of the steam jet instrument. This centenary marks a period when we may review the application of the injector to locomotive practice.

Prior to 1860 locomotive boilers were supplied with water by means of force pumps, which were operated from some point of the engine mechanism, from independent eccentrics or cranks, from the crosshead by steam donkey pumps and in a few cases by auxiliary pumps manually operated. When steam pumps were employed these were usually in conjunction with some form of feed water heating.

Figure 1 gives a typical example of the boiler feed apparatus during the 1840-50 period, the figure showing the " Crewe " type of

* Assistant Motive Power Superintendent, British Railways, Southern Region.

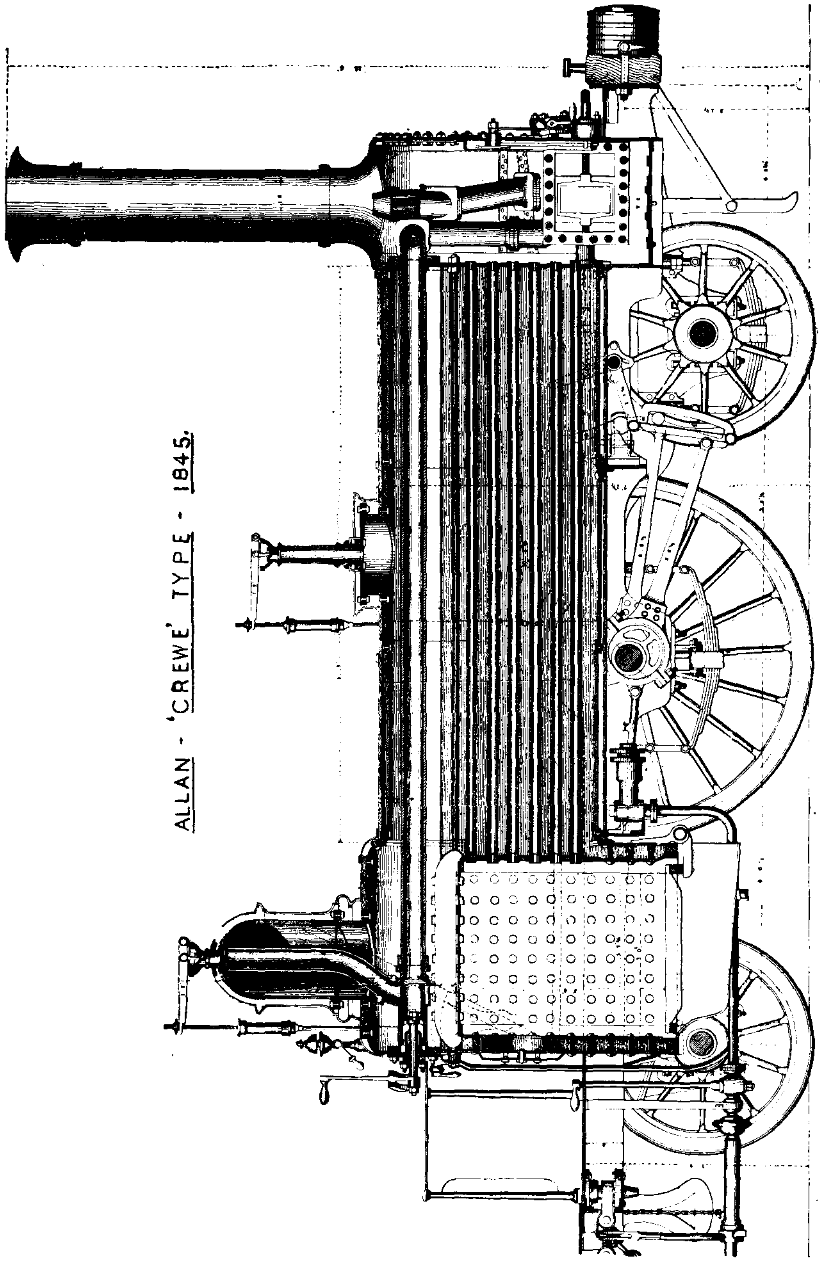


FIG. 1

BOILER FEED APPARATUS, 1845-50 PERIOD

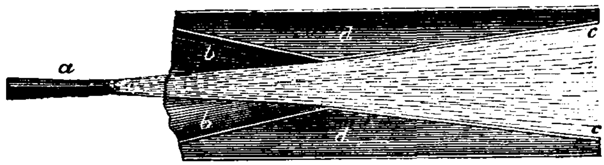
locomotive as built by the Vulcan Foundry near Warrington, in 1848 for the Caledonian Railway. The feed pump valve spindle projected upwards into the footplate and was operated by the engineman's foot as required. The two feed pumps were actuated by a short rod driven from the rear of each foregoing eccentic strap, and the clack boxes were located on the side of the firebox, just below the level of the firebox crown. This type, called the short stroke pump, in comparison with the crosshead or long stroke pump, was also used on Great Western Railway locomotives and was originally attributed to Hackworth.

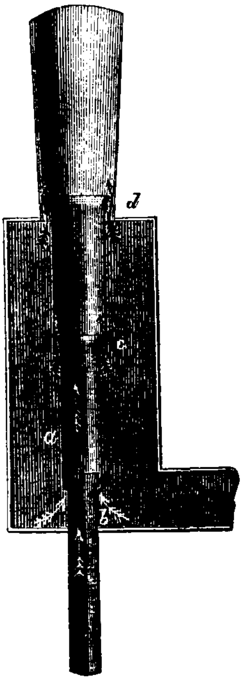
EARLY STEAM JET INSTRUMENTS

The lateral action of fluids whereby one fluid is able to put another fluid in motion has been investigated, among others by the Italian scientist Venturi (1797) and by Nicholson in 1806. In the Venturi law lies the fundamental application of the injector. This law states that water flowing through a pipe of diminishing area loses the pressure which it exerts laterally as it gains in velocity and conversely water flowing through an expanding pipe loses in velocity and regains head or pressure. The foregoing is simply the action of the combined jet of steam and water passing through the combining and delivery cones of an injector.

In the Nicholson patent of 1806 a small jet of steam at high pressure and moving at high velocity was made to entrain a column of air transforming the initial steam jet into a jet of steam and air of large volume and lower velocity but having the same amount of energy. Fig. 2*a* gives a sketch of Nicholson's steam blast in which " A " represents a pipe through which steam passes from the boiler when it proceeds through the pipe " D " carrying along with it a large proportion of common air, which entered through the spaces " B " and this mixed fluid passed hence through " C."

In the Paris patent of 14th August 1818, the Marquis Mannoury D'Ectot gives a survey of the laws governing the transformation of energy which had been investigated by Bernoulli and Euler. In D'Ectot's contrivance (Fig. 2*b*) a fluid passing with a high velocity through a small pipe, which emptied into successively larger pipes, may be made to entrain a fluid at each successive annular opening. One of the applications proposed for this patent was to draw water from wells by different systems, one of which is illustrated in Fig. 2*c*. " A " is a pipe dipping into a water tank or well " L " and terminating in a sphere " K " which communicated by means of a pipe " N " with a chamber " G," into which a jet of steam was conducted which issued through the open pipe " H." The first effect of this jet was to draw air out of the sphere and thereby cause the water to ascend in the pipe " A " from the tank or well into the sphere, whence it passed through the pipe " N " into the chamber " G." The steam jet here encountered the water and was condensed by it through the pipe " K " in the same manner as was done almost forty years later by Bourdon's and Giffard's instruments.





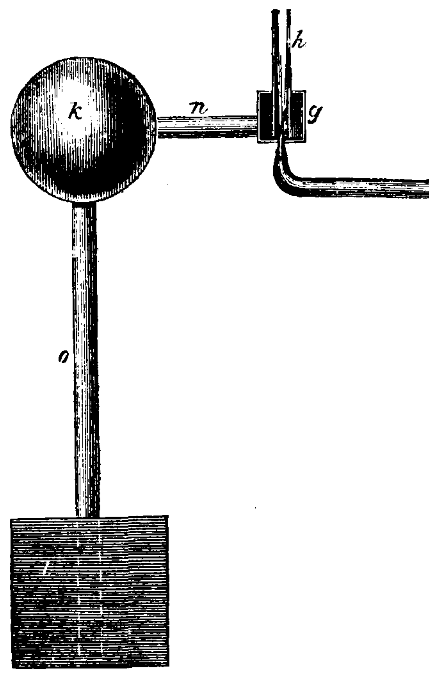


FIG. 2(*a*) *Top*—NICHOLSON'S STEAM BLAST, 1806
FIG. 2(*b*) *Bottom left*—ANNULAR JETS, MANNOURY D'ECTOT, 1818
FIG. 2(*c*) *Bottom right*—MANNOURY D'ECTOT'S INJECTOR, 1818

The experiments introduced between 1818 and 1860 for propelling air and water by jets of steam, whether to produce pressure or exhaustion were substantially reproductions of the foregoing devices and were examples of the principle of the transformation of energy that D'Ectot so clearly expounded and which were earlier expressed by Bernoulli's theorem.

In 1840 Ravard made an improvement of D'Ectot's jets but Bourdon made the greater advance and took out patents in 1848 and

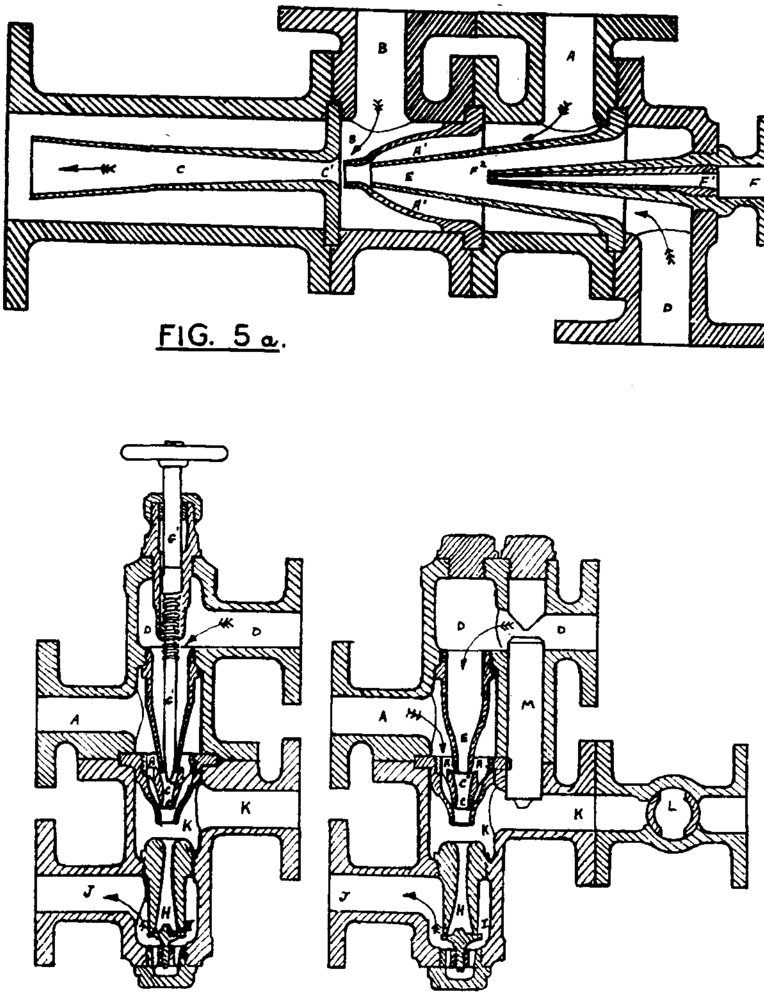


FIG. 5 a.

FIG. 5 b.

FIG. 5 c.

FIG. 5

MORTON'S EXHAUST STEAM INJECTORS, 1867

when he dispensed with the converging steam cone and introduced the divergent type. This latter improvement is credited to Schau, of Vienna, who experimented with steam nozzles of various forms.

SELF ACTING INJECTORS

Messrs. Wm. Sellers, of Philadelphia, made an attempt, like Giffard before them, to make the water regulation of the injector

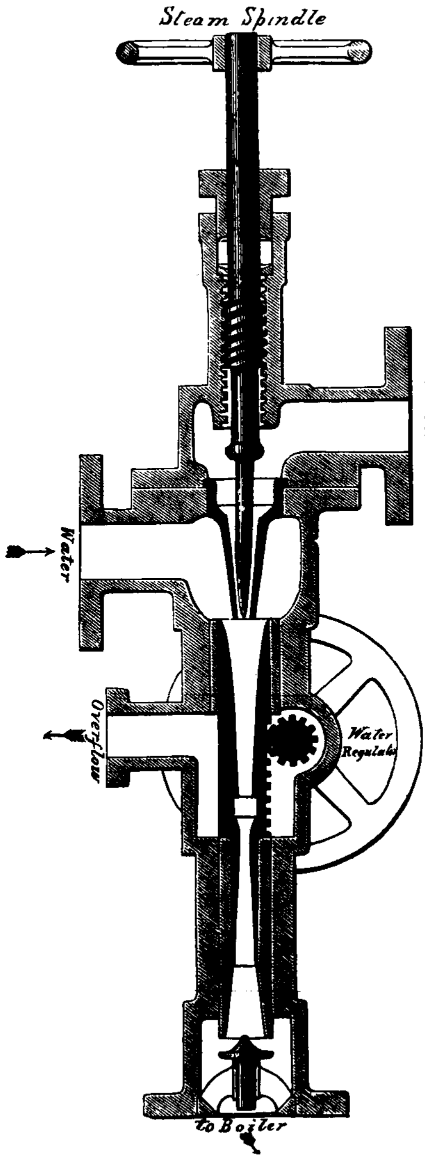


FIG. 4
GRESHAM'S IMPROVED GIFFARD INJECTOR

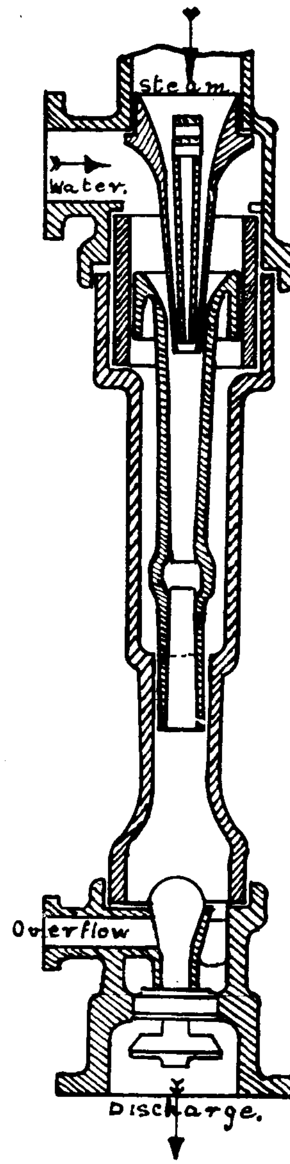


FIG. 4(*a*)
SELLERS' SELF ADJUSTING INJECTOR, 1864

astonished when it was found that water was being fed into the boiler. The Newcastle firm, however, were not so fortunate with the coupling up of the pipes and their sample injector would not function.

Messrs. Sharp & Stewart tried their injector on a stationary boiler at their works and it was later fitted to a ballast locomotive on the St. Helen's Railway, about the middle of 1859. The injector was soon able to displace the feed pump and maintain the water level in the boiler. A larger Giffard injector was then fitted to a goods locomotive on the same railway and Mr. Robinson, of Messrs. Sharp & Stewart, with the assistance of Mr. Cross, the Superintendent of the St. Helen's Railway, carried out experiments with this injector and with another injector made in Manchester, to ascertain the effect of high temperature of the feed water and the effect of vibrations and concussions caused by the brake, on the regularity of the water passing through the injector. Ten injectors were ordered by this railway from Messrs. Sharp & Stewart, and this firm dispensed with pumps altogether on locomotives built for foreign railways. In this country, however, the practice of having one pump and one injector on each locomotive continued for some time. The L. & N.W. Railway were next to use this new water feed apparatus when Ramsbottom fitted injectors on some of his " Problem " 2-2-2 type of locomotives during 1860.

Messrs. Sharp & Stewart secured the patent rights for the Giffard injector in Great Britain and they began to manufacture the injector from patterns obtained from M. Giffard, but they soon set out to improve the instrument from experiments carried out. This firm continued to manufacture injectors till 1888, when they moved their locomotive works to Glasgow.

The American patents for Giffard's injector were obtained by Wm. Sellers, of Philadelphia, who commenced to make injectors in 1860. Messrs. Baldwin were the first locomotive builders in the U.S.A. to fit the injector to locomotives, this being for the Clarksville & Louisville R.R. in September 1860.

In 1864 Andrew Barclay, of Kilmarnock, attempted to improve the injector by creating a higher vacuum in the instrument to enable the water to be lifted more than the three to five feet of the Giffard injector. He used a double nozzle apparatus for this purpose. After being warned by Messrs. Sharp & Stewart regarding his infringement of Giffard's patent, Barclay was later sued and had to pay £300, though he felt he had been unfairly treated and thereafter did not hesitate to give vent to his feelings as, at the same period, he was in the midst of a controversy with Alex. Morton regarding the introduction of the jet condenser.

Soon after the introduction of the injector as a practical unit, modifications of the Giffard principle began and these have been continued unbroken to the present day. The first modifications were carried out by Gresham & Robinson, Patent No. 2784 of 1864, where the combining or condensing cone was made in one and operated by a rack and pinion arrangement (Fig. 4). Further improvement was made by J. Gresham in 1867, Patent No. 3169, and again in 1869

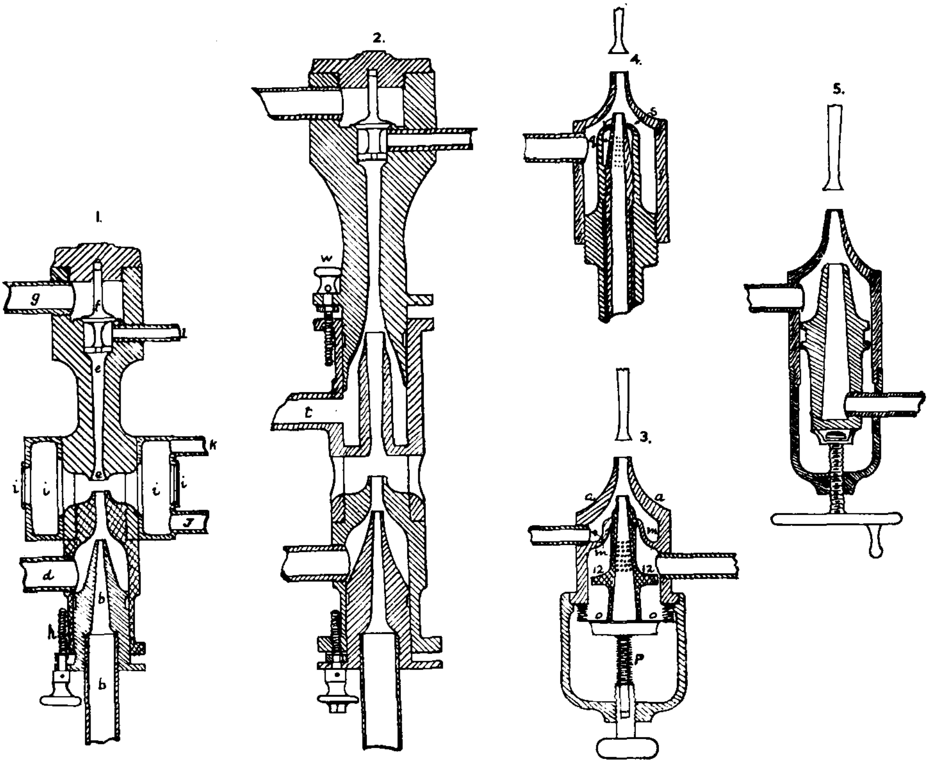


FIG. 3
GIFFARD'S ORIGINAL PATENT, 1858

and water has attained a sufficient velocity and pressure to raise the boiler clack valve and deliver the jet into the boiler. Giffard's injector, therefore, consisted of the discovery that in order to deliver water through an injector into a boiler, the jet must first overflow into the atmosphere. Injectors made before Giffard's patent were generally based on the same principle but were unable to deliver against pressure.

INTRODUCTION OF THE INJECTOR TO LOCOMOTIVE PRACTICE

There are various accounts of how the injector was introduced into England. Probably the most authentic is that two or three samples of injectors came into the hands of the Paris representatives of Messrs. Sharp & Stewart, of Manchester, and R. Stephenson & Co., of Newcastle, who sent them over to their respective firms, but without instructions as to their operation. By good fortune the Manchester firm coupled up the various pipes correctly and were

delivered in relation to the power of the steam jet, and to the smallest diameter of the double mouthpiece " e " is adjusted by means of the regulating screw " h," the effect of which is to increase or diminish the distance between the nozzle " b " and the lower end of the chimney " c " and thereby enlarging or contracting the annular jet of water. The regulation may be made by the apparatus itself as in (3) and for this purpose the nozzle is movable and free to slide within the box " aa," being guided at the upper end by the partition " m " and at its lower end by the four guide arms " nn." The lower aperture " O " is closed by any easy working packing or by a species of metallic bellows " OO." The steam pressure acting upon the apparatus will cause a helical spring " p " to be more or less compressed, the spring being adjusted to suit the pressure of steam employed and the size of the annular jet of water at the entrance of the chimney. The adjustment of the water jet may be accomplished in the manner shown in (4) where the steam jet assumes an annular form issuing from the orifice " g," and forces a quantity of water proportional to the pressure into the space " rs," condensing itself at the same time. This water on entering the chimney receives on the part of the nozzle a further impulse. The whole of the apparatus may be enclosed in an envelope such as shown in (1) " ii " which is filled at the lower part with a small pipe " J " descending again into the tank, in case of a squirting of water at the entrance to the contracting mouthpiece " e." It is also fitted with another pipe " K " at the upper part, so that in case of water from the tank being drawn up too hot, and the whole of the steam being thereby not condensed, the excess of the latter may escape. Openings or windows may also be formed in the outer case to facilitate the examination of the state of the jet and general working of the apparatus, which openings may be covered with glass. If the water in the tank or tender should be too high in temperature to condense the entire quantity of steam issuing from the nozzle, it would be required to divide the actuating steam jet into two parts as shown in (2), the first portion acting as above described, drawing up water and imparting to it only a fraction of the necessary speed and the second portion, arriving by the pipe " t," and having its annual sectional form regulated by the screw " W," would impart to the jet a fresh impulse in the diverging mouthpiece to any point where the ejected water would still possess a portion of the pressure of the boiler. With the portion of this pressure above the atmosphere, the water would condense the fresh amount of steam, which would then no longer act and would thus be introduced into the boiler under the most favourable conditions. This principle may be modified and worked out in varying ways, the water may also be made to flow in the centre, and the steam surrounding it for the first impulse and vice versa, but taking care always to provide an adjusting arrangement for regulating the various sections of the jet and also for acting as a stop cock as shown in (5) Fig. 3.

From the foregoing it will be observed that in Giffard's original patent provision was made for both a hot water injector with two stage admission and for a self adjusting injector, different forms of which were introduced subsequently by injector manufacturers.

Mention has been made of other patents for steam jet pumps. The French engineers Pelleton and Bourdon took out patents, but the main difference between these injectors and Giffard's was the " gap " or distance between the outlet orifice of the condensing or combining cone and the delivery cone, this is the overflow space that communicates with the atmosphere. When starting the injector there is generally more water let into the injector than the instrument can cope with and if there is no communication with the atmosphere the injector will refuse to function and the steam following the line of least resistance would blow back into the tank. By providing an overflow gap, however, between the combining and delivery cones the surplus water is allowed to escape until the combined jet of steam

1857 for types of jet instruments. The similarity of the latter with Giffard's apparatus was so marked that the question of priority arose. It was proved, however, that Giffard was wholly unaware of Bourdon's improvements when he applied for his Paris patent in the spring of 1858. Also Giffard had publicly stated in 1850, seven years in advance of Bourdon's 1857 patent, the theory of his invention, and full credit was given Giffard for the original conception of an injector that could force water into a boiler against the steam pressure.

In this country, Andrew Barclay, of Kilmarnock, and his draughtsman, Alex. Morton, when experimenting with jet condensers, from 1854, also tried to inject water into a boiler against steam pressure, but their apparatus would not function against the boiler pressure.

THE GIFFARD INJECTOR

Henri Jacques Giffard (born 1825, died 1882) graduated from the Ecole Central in 1849. He had made a study of aeronautics and had spent his time in developing light weight steam generators and engines for the propulsion of airships. Giffard was granted patents before May 1858 when letters patent were issued for L'Injector Automoteur, this was followed by the English letters patent and provisional specification No. 1665 of 23rd July 1858. The Academy of Science in Paris granted Giffard the Grand Prix for 1859. From Giffard's drawings a model injector was made by M. Fland et Cie., of Paris, and although considerable difficulty was experienced in making the various cones the first instrument constructed entirely fulfilled expectations.

The following is an abridged copy of Giffard's patent for " Improvements in Feed Apparatus for Steam and other Boilers which Improvements are also Applicable to the raising and forcing of Fluids." :—

With reference to Fig. 3 (1) a vertical section of a simple arrangement of the apparatus is shown. " b " is the steam pipe, which is fitted with a contracting nozzle, receiving the steam direct from the boiler and discharging it in the form of a continuous jet into a small chimney. This chimney is expanded at the bottom so as to admit a free passage of water in the form of an annular jet, which is drawn up the pipe " d " from the tank by the action of the steam jet in the chimney, and is thus brought into immediate contact with the steam, which transmits an impulse to it and simultaneously raises its temperature, thus there will issue from the chimney into the air a jet of water. A short distance above this chimney is a double mouthpiece " e " the lower end of which is gradually contracted upwards so as to unite in one compact vein the liquid jet which issues from the mouth of the chimney in a more or less broken state, whilst the upper portion of the mouthpiece is expanded gradually, so as to cause the jet to lose successfully and without shock to the liquid, the speed it had attained in order that it may arrive at the upper portion of the apparatus at a pressure at least equal to that of the boiler without possessing any notable speed and consequently without loss of kinetic energy. Above the expanding mouthpiece " e " or at any other convenient part of the apparatus, is fitted a check valve " f " and above this valve is the pipe " g " which conducts the feed water to the boiler. Below the valve " f " is a branch pipe "t" furnished with a stop cock, upon which pipe a pressure gauge may be fitted when required for experiments. The suitable portion of water to be

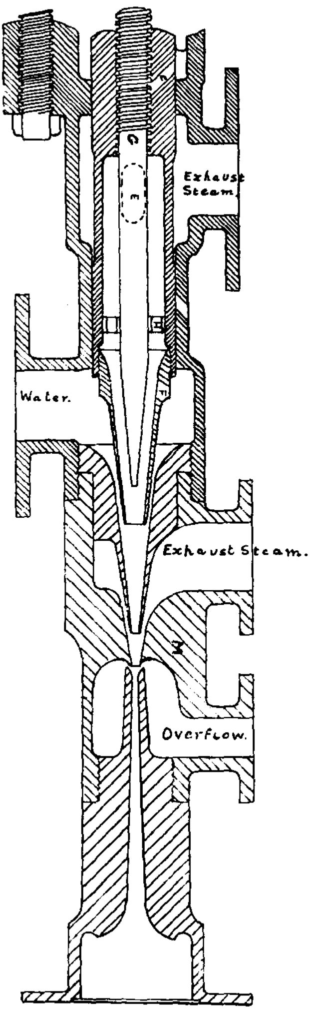
automatic. In Fig. 4*a*, the combining and delivery cones, instead of being operated by a screw or rack and pinion, had, at the feed water end, a piston sliding with an air-tight fit in a metallic cylinder. The overflow chamber opened into a compartment, the upper end of which was covered by the above piston. When the supply of feed water was too great some would escape by the overflow into the compartment, causing an increase of pressure therein, thereby raising the piston and reducing the water supply. Should the water supply be too little, some of the water in the compartment would be induced into the delivery cone through the overflow gap and thus reduce the pressure in the compartment, allowing the piston to descend and admit more feed water. Here also the hollow steam spindle made its appearance for the purpose of lifting the feed water for starting. This injector always delivered the maximum quantity of feed water on account of its automatic water regulation.

EARLY EXHAUST STEAM INJECTORS

By the late sixties, when the injector was widely used, it was but natural that an attempt would be made to economise by using the latent heat in steam, which had performed a previous duty, to work the injector. In 1867, Alex. Morton (late of Messrs. A. Barclay & Co., of Kilmarnock), of Messrs. Morton & Thomson, of Glasgow, took out an interesting Patent (No. 2106) dealing with an improved locomotive exhaust arrangement and for injectors " made more economical in their working than has heretofore been the case." Morton had been working on the exhaust steam injector since 1863, and in his patent five different types of exhaust or low pressure injectors are shown. Morton's jet condenser and injector experiments dated from the early 'fifties and he can almost be called the " British Giffard." Fig. 5*a* shows Morton's injector for the utilisation of exhaust steam. " A " and " B " were the exhaust steam pipes from the two cylinders, " C " the induction tube and " D " the water inlet which took the form of a central jet at the nozzle " E." This central jet of water was maintained when the engine was working, by the alternate discharge of the steam from the cylinders at the pipes " A " and " B." On starting the injector, the jet of water could be produced by a central jet of supplementary live steam through the pipe " F " and the duplex nozzle " F." Once the injector was started it was intended to cut off the supply of live steam. It should be mentioned, however, that there is no record of Morton's exhaust injectors being applied to locomotive practice. The arrangement shown in Fig. 5*b* was adopted for raising water from a depth below the injector. The inducing tube " C " was in two parts and a central spindle " G " could be used to regulate the water when the steam pressure was variable. In the injector shown in Fig. 5*c*, Morton used an automatic arrangement for regulating the flow of water in accordance with the variable steam pressure. A cylindrical piston " M " was fitted to work in a chamber placed eccentrically to the apparatus and in working the injector the regulator cock " L " connected to the overflow branch " K " was open until an unbroken stream of water passed through it, when the

cock was closed and the water, if still accumulating in excess in chamber "K," forced up the piston "M" which caused its top end to close partially the water inlet passage "D," until the regulating of the stream of water to that of the pressure of steam was established.

In the early 'seventies Korting experimented with injectors using exhaust steam drawn into the combining cone for which a patent was granted in 1872. Metcalfe and Davies obtained patents in 1876 and 1877, Nos. 2984 and 591 respectively, for injectors actuated by exhaust steam. In the latter patent it is stated that the improved injector differed from ordinary injectors in having no communication with the



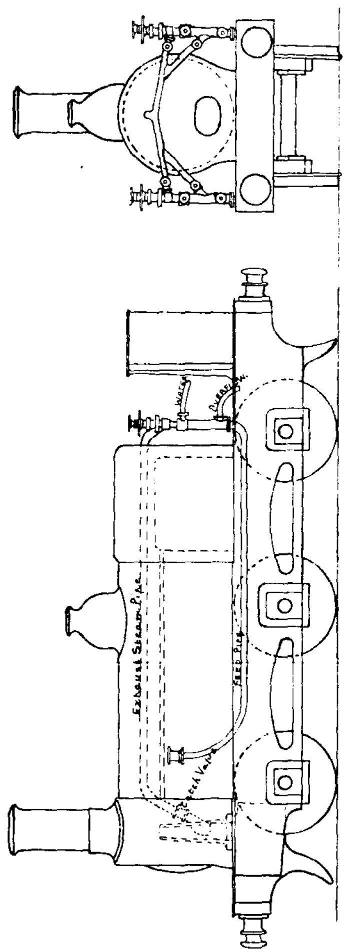
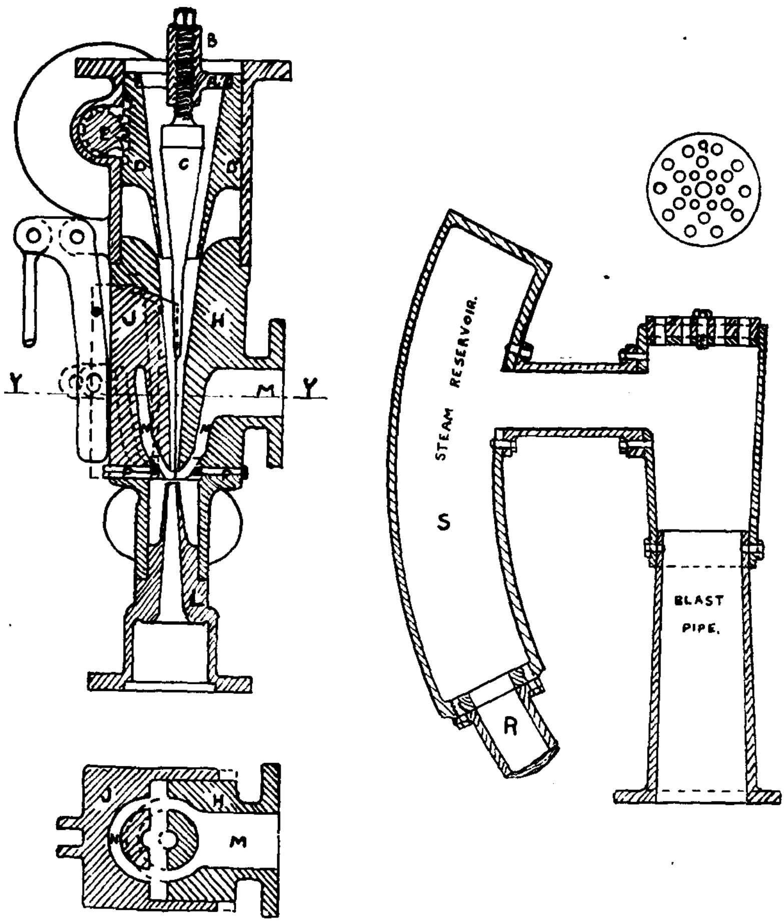


FIG. 6(a) *Top*—EXHAUST STEAM INJECTOR, HAMER, METCALFE AND DAVIES, 1876 AND 1877

FIG. 6(d) *Bottom*—DITTO, GENERAL ARRANGEMENT

" live " steam space of the boiler and the cross sectional area of the steam passage or nozzle is much larger in proportion to that of the water passage and to that of the " throat " or smallest section of the discharge cone than is the practice in ordinary injectors, thus providing for the larger volume of the exhaust steam required, to pass about the same weight of steam as would have been used with " live " steam. In Fig. 6*a* one form of the exhaust steam injector is shown. The steam branch is connected with the exhaust pipe or ports of the



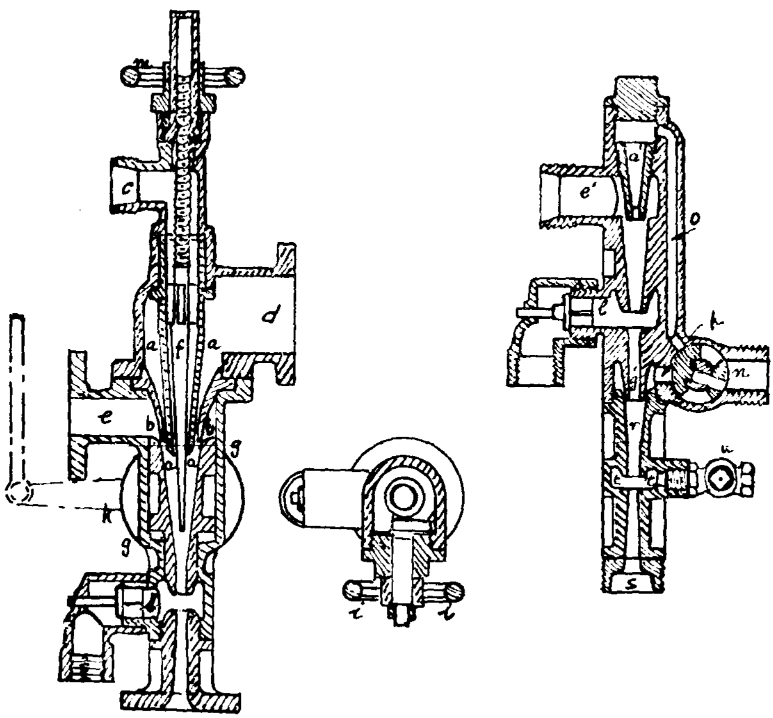
SECTION ON Y.Y.

FIGS. 6(*b*) (*left*) AND 6(*c*)

EXHAUST STEAM INJECTOR, HAMER, METCALFE AND DAVIES, 1876 AND 1877. FIG. 6(*b*) SHOWS THE SPLIT NOZZLE. FIG. 6(*c*) SHOWS THE BLAST PIPE ORIFICE COVERED BY A PERFORATED PLATE

locomotive and receives part of the exhaust steam as it escapes to the atmosphere.

In the year following, Hamer, Metcalfe and Davies obtained Patent No. 4014 for exhaust steam injectors. This patent is our first contact with the split nozzle combining cone, operated, in this case, for starting only, by rods and levers. The split nozzle is shown in Fig. 6*b* where " A " is the exhaust steam inlet, at " B " was a nut for adjusting the spindle " C " to regulate the size of the opening through the steam cone " D." The position of the steam cone was made in two parts " H " and " J " where the part " H " was screwed in the injector casing, and was formed so as to receive the slide " J." The movable part " J " was actuated by a lever as shown, this part being drawn backwards so as to leave an opening for starting, giving an increased free section for that part of the cone. The exhaust steam and water being admitted to the injector passed through the combining cone and as soon as this was effected the sliding part " J " was forced forward by the lever and formed a complete cone of the proper size for continuous working of the injector. The same patent gives an improvement in the exhaust pipe (Fig. 6*c*). This consisted of enclosing the blast pipe orifice by a perforated plate, upon which revolved a



FIGS. 7(*a*) (*left*) AND 7(*b*)
HALLAM AND SHEPHERD'S EXHAUST STEAM INJECTORS, 1881

similar plate having corresponding holes, such holes being of sufficient area to allow the whole of the exhaust steam to escape through them. When the exhaust steam injector was at work the perforated plates were revolved in order to diminish the area of the holes to an extent corresponding to the quantity of steam used by the injector. Fig. 6*d* shows the arrangement of the injectors and exhaust steam pipes on the locomotive.

In 1880, Mr. Davies added a hinge to the moveable portion of the combining cone and in this patent (No. 316) the first record of the practical use of the compound injector is to be found (see Fig. 26). The exhaust and live steam injectors were placed end to end, the former delivering into the latter, the steam was supplied through a three-way valve " K " and channel " g," entering the injector as an annular jet, the valve " K " also served as a relief valve for starting. The supply of water was regulated by the hand wheel " d " which moved the combining cone axially by means of an eccentric pin. This injector was widely used and was known as the " B " type exhaust steam injector.

An exhaust steam injector that could also be used as a live steam injector was patented by Hallam and Shephard, No. 4537 of 1881, this being an improvement on Patent No. 4803 of 1878 and is shown in Fig. 7*a*. The injector consisted of a double injecting nozzle, " a " being the inner and " b " the outer nozzle, " c " was the inlet for live steam, " d " the inlet for exhaust steam and " e " the inlet for water. The inner nozzle was provided with a regulating spindle " f " and the receiving nozzle " g " was fitted to a slide-like piston which was acted upon by means of an eccentric " h " which could be turned by the wheel " i " to adjust the position of the inlet mouth of the receiving cone. When no exhaust steam was available the exhaust passage was closed, the spindle " f " was raised to admit live steam to the inner nozzle " a " and the apparatus acted as an ordinary injector. The regulating spindle " f " could also be turned to admit a supply of live steam to assist the exhaust steam when necessary.

In the same patent is shown a form of two stage admission of steam to the injector. In Fig. 7*b* " a " was the first steam nozzle which received steam through the valve " n " and passage " o," and " e " was the inlet for water. The valve " n " also communicated with a passage " p " which led into a space at the lower end of the receiving cone " g." This valve could be rotated so as to supply steam to either or both ports " o " and " p." This form of injector could feed the boiler with the receiving water of high temperature.

EARLY INJECTORS OF RAILWAY MANUFACTURE

When the injector came into general use on the railways, different companies commenced to design their own injectors. In 1874, Mr. Webb, of the L & N.W. Railway, patented a non-automatic injector in which he dispensed with the general practice of having the injector delivery pipe outside the boiler, thereby avoiding the loss of heat due to the cooling of the feed. Some time later Webb replaced this injector

by an automatic type in which all the nozzles were fixed and rigid, the automatic action being attained by an independent sliding valve carried on the injector casing. This valve controlled a chamber surrounding the supplementary overflow gap in such a manner as to allow the free escape of steam and water at starting the injector and closing the chamber after the injector started. This arrangement of

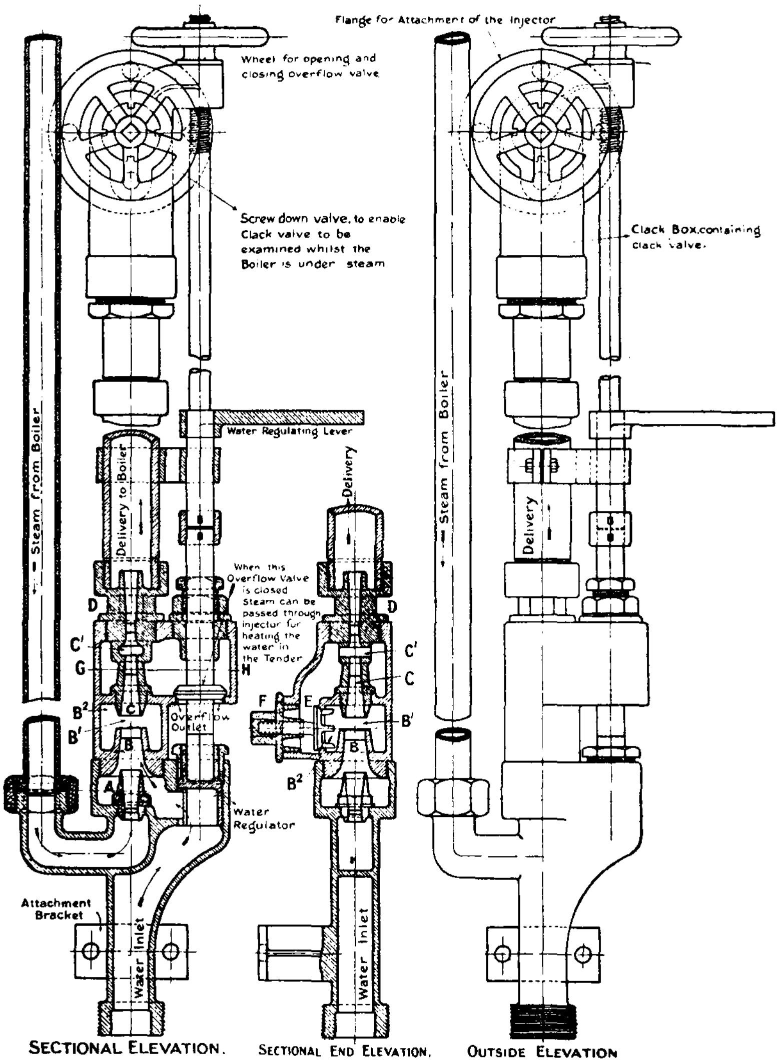


FIG. 8

WEBB'S SELF-ACTING INJECTOR, L. & N.W.R.

fixed nozzles and an independent sliding valve formed the principle of White's patent self acting injector also used on the L. & N.W. Railway. Fig. 8 illustrates Webb's later automatic injector. The automatic action was controlled by the valve " E " which prevented air entering the chamber " B " as this would break the jet and interfere with the efficient working of the injector. The valve " E " was kept closed by the combined action of a spring and by the continuous vacuum which was maintained in the chamber " B " while the jet was passing to the boiler.

In the 'seventies the Caledonian Railway used a form of injector called, from its shape, the " barrel " type (Fig. 9*a*). This injector

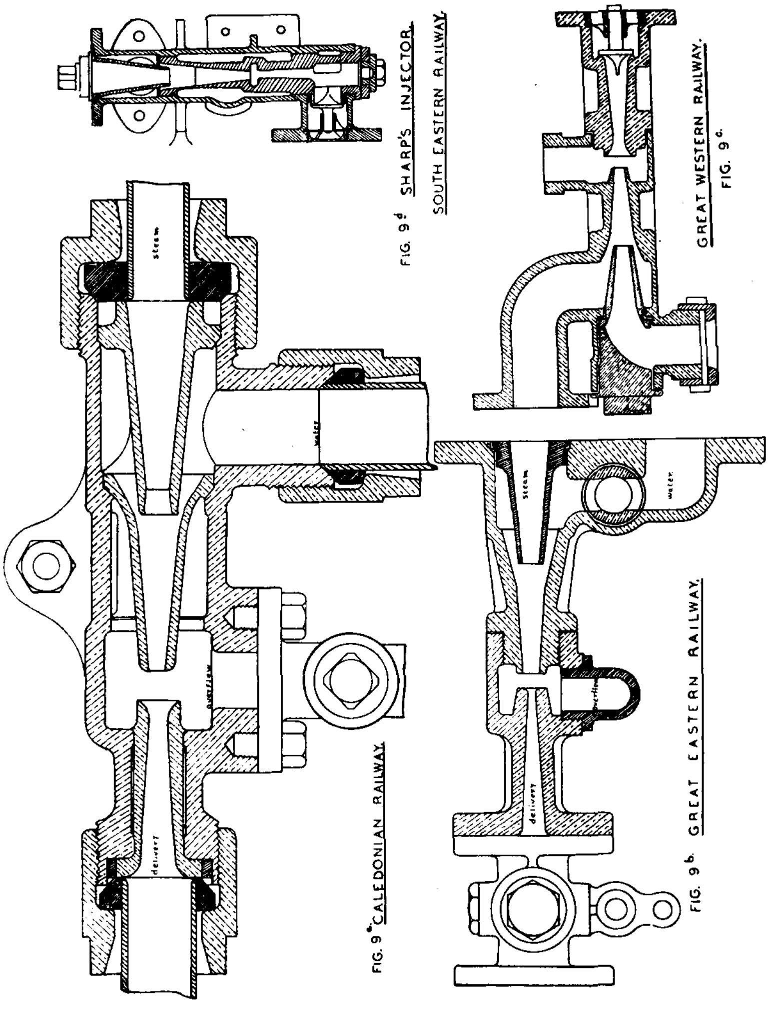


FIG. 9

NON-AUTOMATIC INJECTORS IN USE ON VARIOUS RAILWAYS (CIRCA 1878)

was later improved by Dugald Drummond. The injector was non-automatic and had no screwed details, the whole assembly being secured by the steam and delivery pipe coupling nuts at each end of the injector. The steam and combining cones were cast in one part. An improved type of this injector used separate cones and had a wide application on various railways, the injector still being in use on the Scottish and Southern Regions of British Railways.

The Great Eastern Railway used a non-automatic injector as shown in Fig. 9*b*. Here the injector was made in two parts and contained its own regulating valve, but only one of the two injectors fitted to each locomotive had a screw-down overflow valve, the object of which was to close the overflow aperture and admit steam to the water in the tank when the safety valves were blowing off. A non-return delivery valve was placed in a casting bolted to the delivery cone, this valve being fitted with a pet cock.

Figure 9*c* illustrates the type of non-automatic injector used by Wm. Dean on the Great Western Railway. The combining cone, overflow pipe flange, and water and steam pipe flanges were contained in one casting. The steam cone was kept in position by a screwed plug shaped to provide a continuous contour to the steam flow. The back pressure valve, fitted upon the end of the delivery cone, guided the water from its previous direction down the cone into the chamber beyond the valve without producing eddies. A restarting injector with split nozzle combining cone later became standard on the G.W. Railway.

Sharp's injector was widely used in the 'seventies and 'eighties and Fig. 9*d* shows this type of injector as used on the South Eastern Railway.

HOT WATER—COMBINATION—LIFTING AND AUTOMATIC INJECTORS

In Patent No. 4887 of 1877 (Fig. 10) Alex. Friedmann, of Vienna, made improvements on the injector in order to take higher temperature feed water, the improvement being made on earlier Friedmann injectors. The upper part of the intermediate cone " Z " fitted closely against the inner circumference of the injector casing to form a reservoir " r." About the middle of the length of the combining cone a hole " O " was drilled which communicated with the space " i." This space " i " formed on the external surface of the combining cone was in communication with the overflow chamber and the overflow gap " w." By these improvements it was claimed that extremely hot water could be supplied in comparison with the ordinary injector. This is also the first instance in which holes or slots appeared on the combining cone of the injector.

Also in 1877, Sheward and Gresham in Patent No. 4436 described an injector (Fig. 11) that could be taken apart easily. This consisted of a casing " a " which had branches for steam, water and delivery. The passage forming the combining and discharge cones was formed in one piece " b " in such a manner that the steam nozzle " c " could

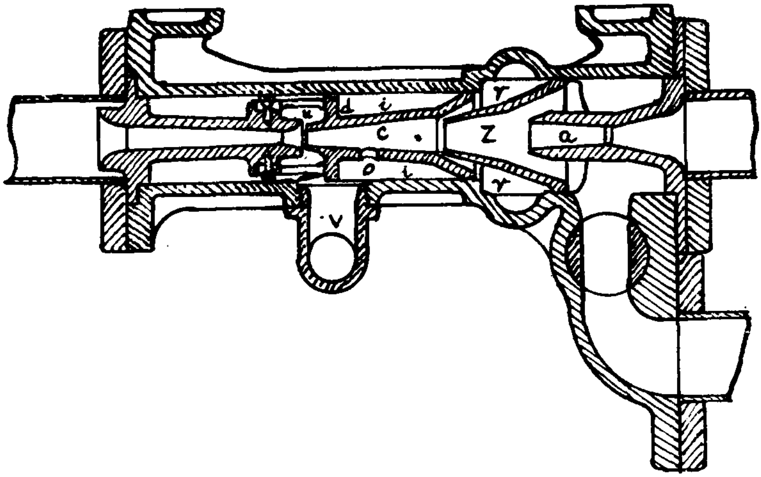


FIG. 10
FRIEDMANN'S HOT WATER INJECTOR, 1877

be screwed in as shown. The steam nozzle end of the central part " b " being the smallest in diameter. The lower part of the charge cone in the part " b " was closed by a plug, which, when removed, allowed the passages to be examined.

Gresham and Craven introduced their famous lifting combination injector in 1884, on which there were no pipes under pressure, the steam valve and discharge valve being combined in one casing with the injector and all the cones could be extracted as described above. Fig. 12 shows this injector in which the automatic or restarting action was obtained by use of a small loose cone forming the lower portion of the combining cone. The injector was located on the boiler back plate and an internal steam pipe from the boiler dome conveyed steam to the injector steam valve and the feed water was introduced into the boiler via an internal delivery pipe. This type of injector,

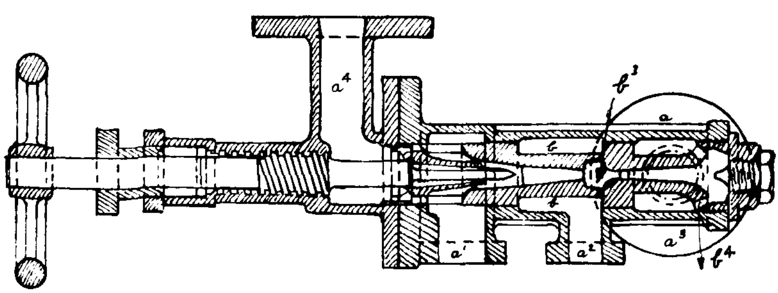


FIG. 11
SHEWARD AND GRESHAM'S INJECTOR, 1877

which is still in use, had probably more popularity with enginemen than any other single injector and was adopted as standard on many railways.

In 1881 Budenberg and Schaeffer patented an injector (Patent No. 1593) which was capable of working with hot feed water, this is shown in Fig. 13*a* and is somewhat similar to Friedmann's injector. The water inlet was divided in two parts "A" and "A¹," and the condensing chamber "B" had an additional nozzle "C" the flange of which was sealed for a part of its circumference on the inner end of the partition dividing the water inlet and the point of which was inserted within the combining nozzle "D." This injector was an improvement on the original Budenberg injector Patent No. 327 of 1874.

Holden and Brooke took out a series of injector patents in 1883 and three years later they patented their rigid nozzle exhaust injector in which the live steam supply was automatic. Later the influx automatic injector appeared, some of which were of the combination type, and in 1888 they introduced the one movement system of steam and water control, a later design of which is shown in Fig. 14.

In the Brooke and White Patent No. 4430 of 1883, three types of injectors are described of which two are illustrated in Figs. 13*b* and 13c. Here the lifting tube between the steam nozzle and the combining nozzle was of parallel bore. When the injectors were at work,

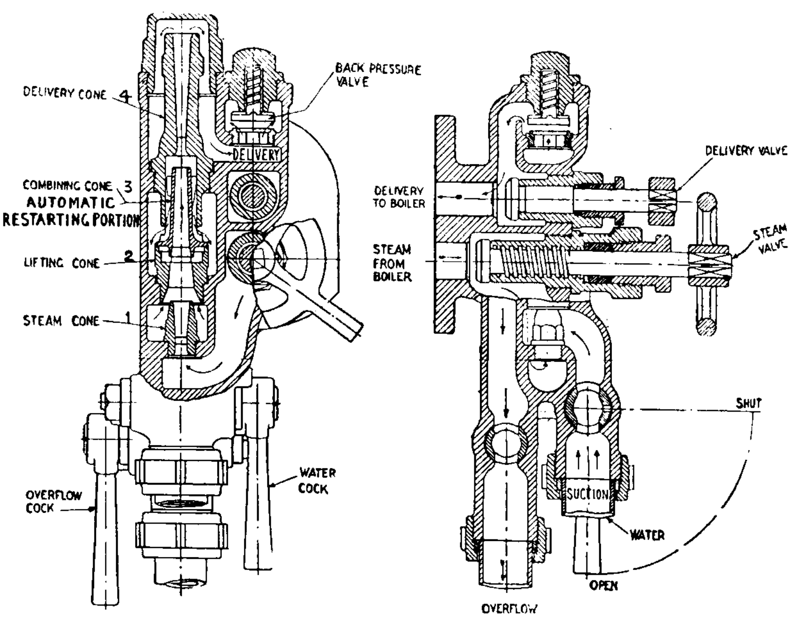


FIG. 12

GRESHAM AND CRAVEN'S LIFTING COMBINATION INJECTOR, 1884

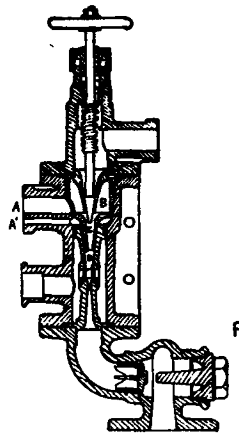


FIG. 13 a.

1881 - BUDENBERG & SCHAEFFER HOT WATER INJECTOR.

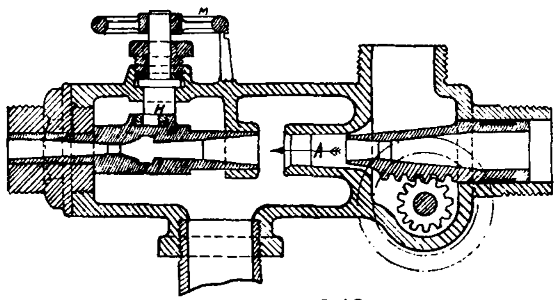
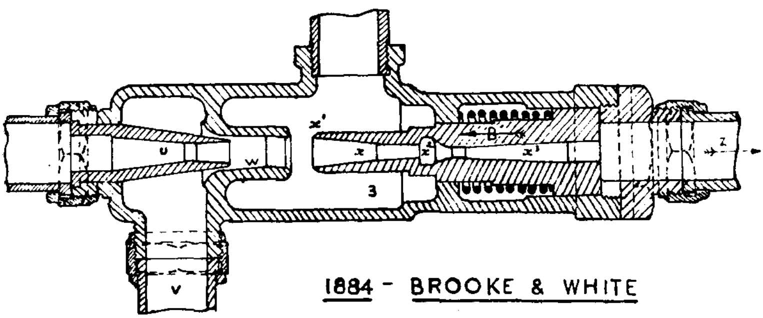


FIG. 13 b.



1884 - BROOKE & WHITE AUTOMATIC INJECTORS.

FIG. 13 c.

FIG. 13

after the water had been lifted, the end of the combining cone was closed against the end and formed a junction with the lifting tube leaving sufficient space for the water and steam to escape. In Fig. 13*b* it will be observed that the water supply could be adjusted by the rack and pinion on the steam cone, giving this cone an axial movement.

Holden and Brooke in Patent No. 2659 of 1884, introduced a lifting automatic injector (Fig. 15*a*). When the supply of steam or water was interrupted, it would cease to pass along the combining and delivery tubes and would escape from the supplementary overflow

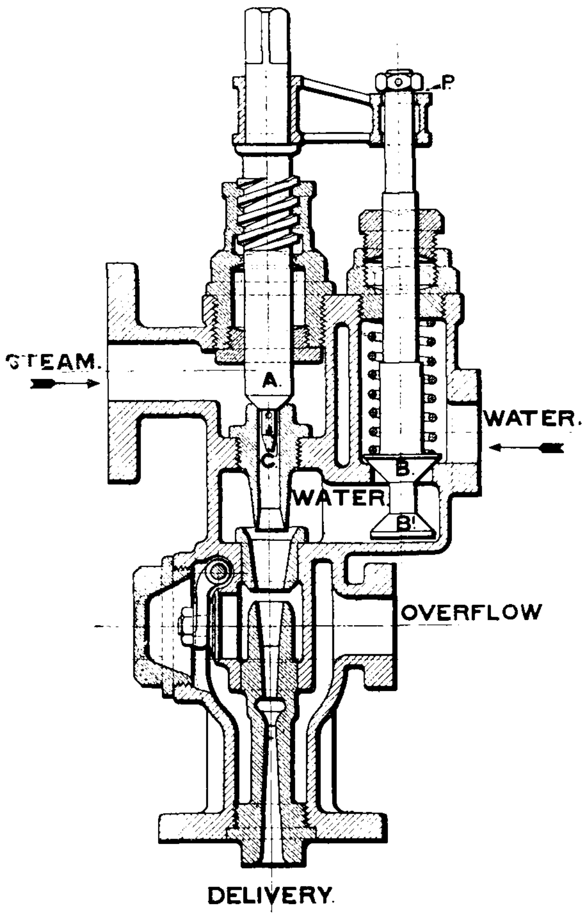
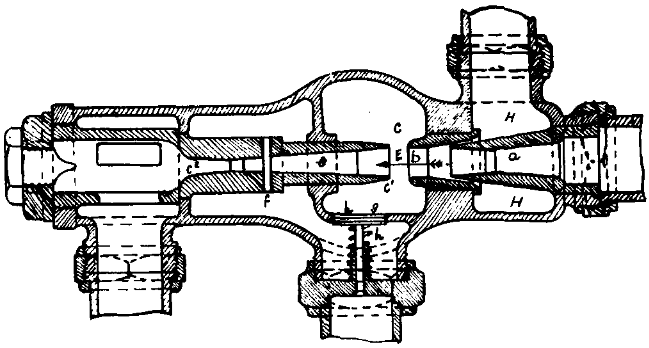


FIG. 14
BROOKE'S "ONE MOVEMENT" SYSTEM



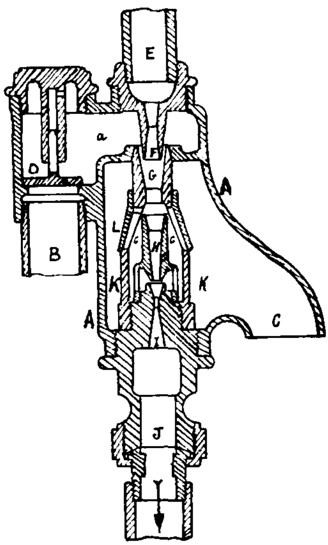


FIG. 15(*a*) *Top*—HOLDEN AND BROOKE'S PATENT LIFTING AUTOMATIC INJECTOR, 1884

FIG. 15(*b*) *Bottom*—MCELROY AND CONNETT'S AUTOMATIC INJECTOR

" E " and pass through the overflow " h " until the jet was reformed. Thus, by using the supplementary overflow " E " in conjunction with the valve " h," the injector was rendered automatic. For use in districts where the feed water was bad Holden and Brooke introduced a split cone injector in which the combining and delivery cones were split in two longitudinal sections and bolted together. These could be taken apart to facilitate cleaning.

The Americans, McElroy and Connett, in the English Patent No. 6525 of 1887, described a lifting injector (Fig. 15*b*) with an automatic overflow valve and a check valve in the feed pipe. Steam was admitted to the injector and passed through chamber " K," the lifting cone " G " and acted on the inner face of valve " L " and passed to the overflow. This created a vacuum and the water rose in pipe " B " by raising the valve " D " and passed through the lifting cone to the overflow. As soon as the jet was established the valve " L " would drop and water left in casing " K " would be drawn into the discharge cone. Should the vacuum be destroyed for a moment, the valve " D " would close preventing the sudden rush of water from chamber " a " and the water would thus be held in the chamber until the vacuum was re-established.

Hopkinson's, of Nottingham, in Patent No. 16169, of 1891, showed a form of automatic injector in which the cones were cast in one piece. Hinged plates were used to relieve the jet in the combining cone, or, as in one case, the nozzle was split. Fig. 15*c* shows an exhaust steam injector described in the same patent. A chamber " G " surrounded the ends of the suction and force cones " C " and " D " and had one or more outlets " G^1," each outlet being covered by a plate " G^2." Below the cone " D " the cylinder " F " formed a chamber " H " provided with perforations " h " which relieved the cones " C " and " D " of water. The action of this injector was the same as an ordinary injector.

Ottocar Lindemann, in Patent No. 19,861 of 1891, described an injector (Fig. 15*d*) in which the action of the sliding combining cone or flat nozzle was replaced by dividing the combining cone for the first overflow, a flap valve closing this aperture when the injector started. Two steam nozzles were also employed, the ring shaped jet from the first nozzle produced a partial vacuum in the combining nozzle. This vacuum was not appreciably affected by the jet of steam which was issuing from the central steam nozzle as the steam jet from both nozzles had a free escape through the overflow. The first outside steam cone served in some degree as a regulator when the injector worked with varying steam pressure, for, with rising steam pressure, it supplied more water, and with falling steam pressure less water to receive the necessary impetus from the steam issuing from the central steam cone.

The Alex. Friedmann Patent No. 630 of 1893 eliminated all moving parts inside the automatic injector, such as sliding cones, flap nozzles and hinged valves. Fig. 15*e* illustrates the original patent, this principle of overflow slots and double steam nozzle is practically the same as is used in the modern " Monitor " injector.

Friedmann states in his patent that the invention has for its object the elimination of all moving parts within the injector and consists of an improved construction whereby all nozzles are rendered fixed. The injector is provided with two steam nozzles " A " and " B " of which " B " surrounds " A " so as to form an annular orifice between the two, and it communicates with the interior of " A " by a number of small lateral holes, so that in opening the steam valve, the steam

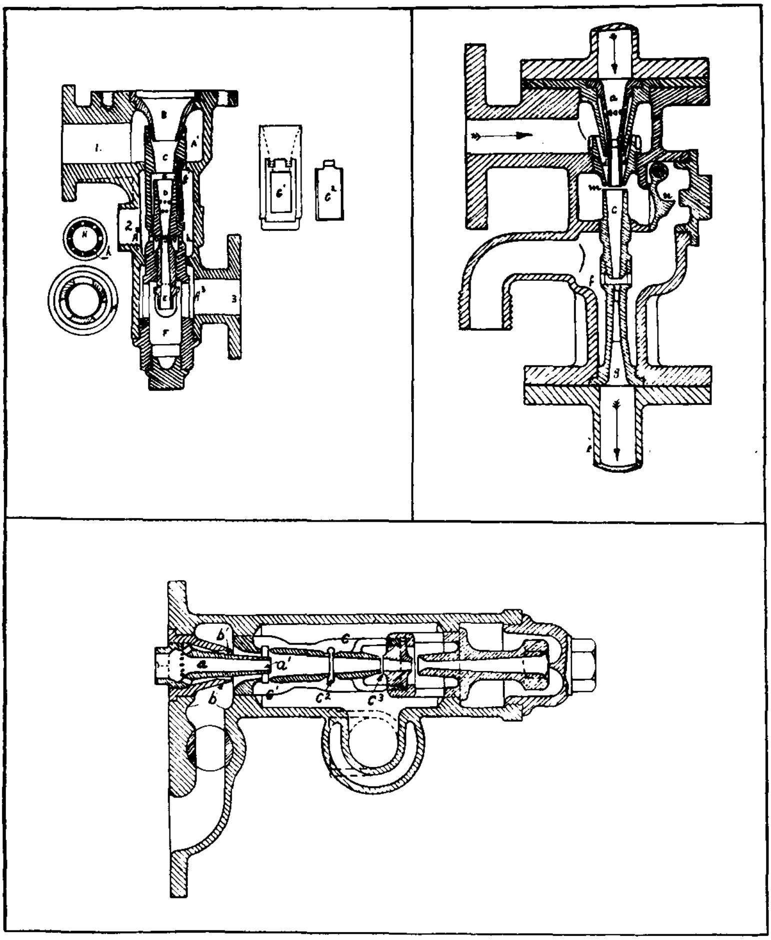
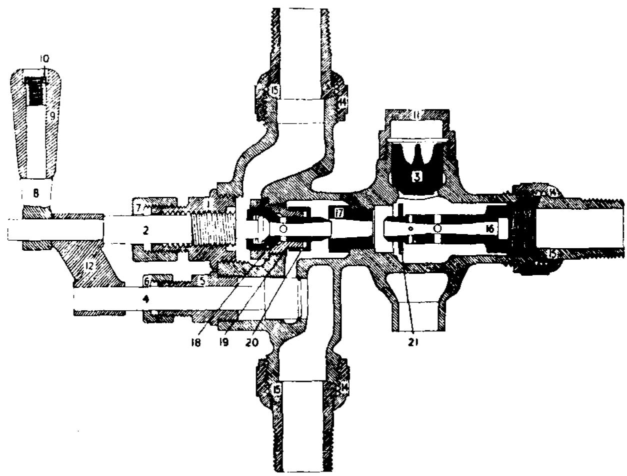


FIG. 15(*c*) *Top left*—HOPKINSON'S PATENT EXHAUST STEAM INJECTOR, 1891

FIG. 15(*d*) *Top right*—OTTOCAR LINDEMANN'S PATENT AUTOMATIC INJECTOR, 1891

FIG. 15(*e*) *Bottom*—ALEX. FRIEDMANN'S PATENT AUTOMATIC INJECTOR, 1893

issues simultaneously through the opening " a^1 " of the central nozzle " a " and through the annular opening " b^1 " of the nozzle " b." The condensation nozzle " c " has a number of inlets " c^1, c^2, c^3 " as shown. The sum of the areas of these openings must be equal to the areas of the steam jet openings " a^1 " and " b^1," in order that in the result of the breaking of the water jet, the freshly entering steam may find sufficient space for issue, in order thereby to enable the water to be drawn up again and to restart the feed.



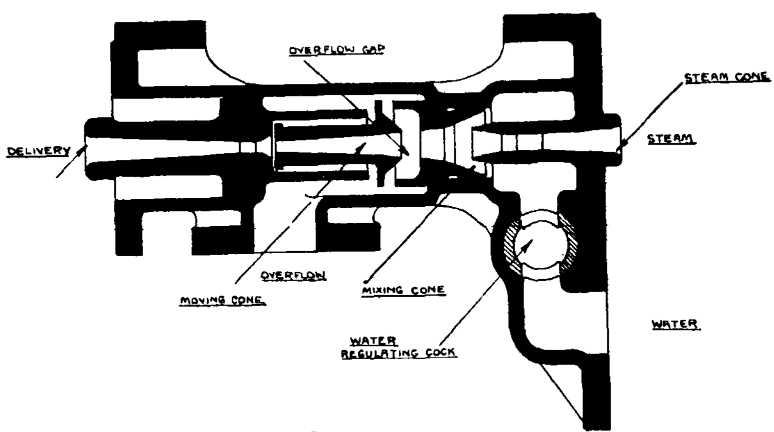


FIG. 16 (*Top*)
" BUFFALO " LIFTING INJECTOR, GREEN & BOULDINGS LTD., LONDON
FIG. 17 (*Bottom*)
GRESHAM AND CRAVEN'S STANDARD FLOOD INJECTOR

The Buffalo Lifting Injector of Green & Bouldings Ltd., London, also dates from this period and is shown in Fig. 16, where the one movement principle for operation of steam and water supply was employed. When the handle " 8 " was turned the steam jet " 18 " was slowly withdrawn off its seat and at the same time withdrawing the water spindle " 4." A partial vacuum having been formed, water passed into the injector and through the suction jet " 17 " lifting the overflow valve " 3 " and so out through the overflow. When the correct water-steam ratio was established, the combined jet passed through the combining cone " 16," the overflow valve dropped to its seat and the feed commenced. The ring " 21 " on the end of the combining tube was drawn back on to its seating in the body of the injector. This ring was most important and proper working could not be achieved without it.

The standard flood injector used by many railways is illustrated in Fig. 17, this having the sliding combining cone of the Gresham and Craven pattern. The injector is non-lifting and is usually placed behind the main footstep below the tank level.

After the spate of injector patents from the 'seventies to the 'nineties, locomotive injectors in this country evolved into three standard types for automatic action, these having either the moving combining cone or the split combining cone or in a lesser degree the divided combining cone with the use of a flap valve controlling the second or supplementary overflow.

COMPOUND INJECTORS

Among other forms of injectors that made their appearance at intervals was the double cone or compound injector. With the ordinary injector it was found that the temperature of the water feed had to be decreased as the boiler pressure increased. The compound injector was devised with the object of supplying feed water to the boiler at a temperature above boiling point, this type of injector being simply an ordinary injector feeding water into another injector under pressure, and this greatly counteracted the retarding effect of high boiler pressure with its high temperature steam. The compound injector was common on the Continent and in America where they were called " Inspirators."

An English make of the double tube or compound injector is illustrated in Fig. 18. This injector which has been on the market for the past sixty years is the " Buffalo " Class A injector manufactured by Green & Boulding Ltd. The injector is shown about mid-position of its action. When starting, the hand " 13 " must be right home, over to the left, so that the steam valve " 2 " is on its seating and consequently the overflow spindle " 19 " is further off its seat than shown. In operating the injector the handle is pulled out slightly after the water valve is opened. This pulls the steam valve a little off its seat but the plug part prevents any steam travelling through the steam tube " 24," steam passes down into the lifting jet " 23 " and emerges at a pressure about one-third boiler pressure, it flows

mostly through the combining tube " 25," past the overflow-valve " 18 " to the atmosphere. Some of the steam, however, passes through the jacket around the overflow valve spindle and out through the overflow nozzle. Having completed the lifting part of the operation the starting handle is pulled right out. The steam valve

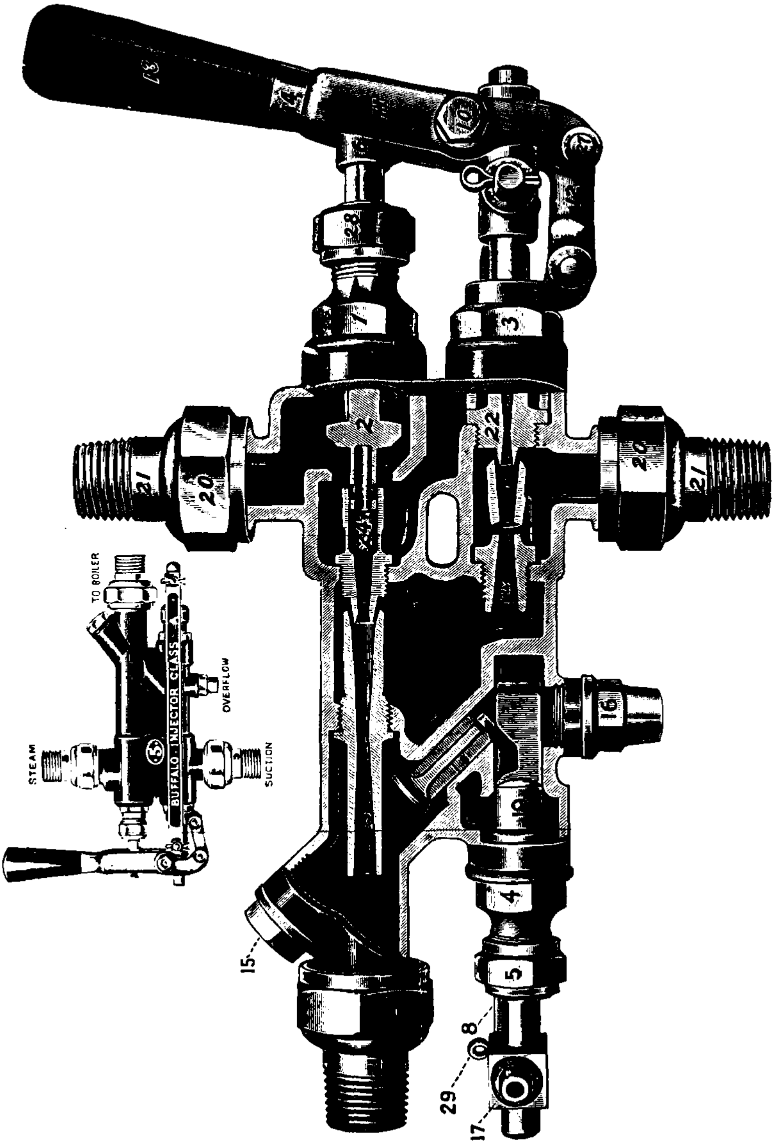


Fig. 18
Buffalo Class " A " Injector

then comes right out of the steam tube and the steam passes through this tube forcing the water through the combining tube. At the same time, due to the linking of the mechanism by means of slide bars, the overflow valve spindle moves over to the right and allows the overflow valve to drop on to its seat and the feed is established. This is a positive type of injector, i.e. it will not start automatically if the feed is interrupted.

As previously mentioned, one of the first compound injectors was the type " B " exhaust steam injector of Davies and Metcalfe (Fig. 26), here the lifter portion was an exhaust steam injector and the forcing portion an ordinary live steam injector. It is worth

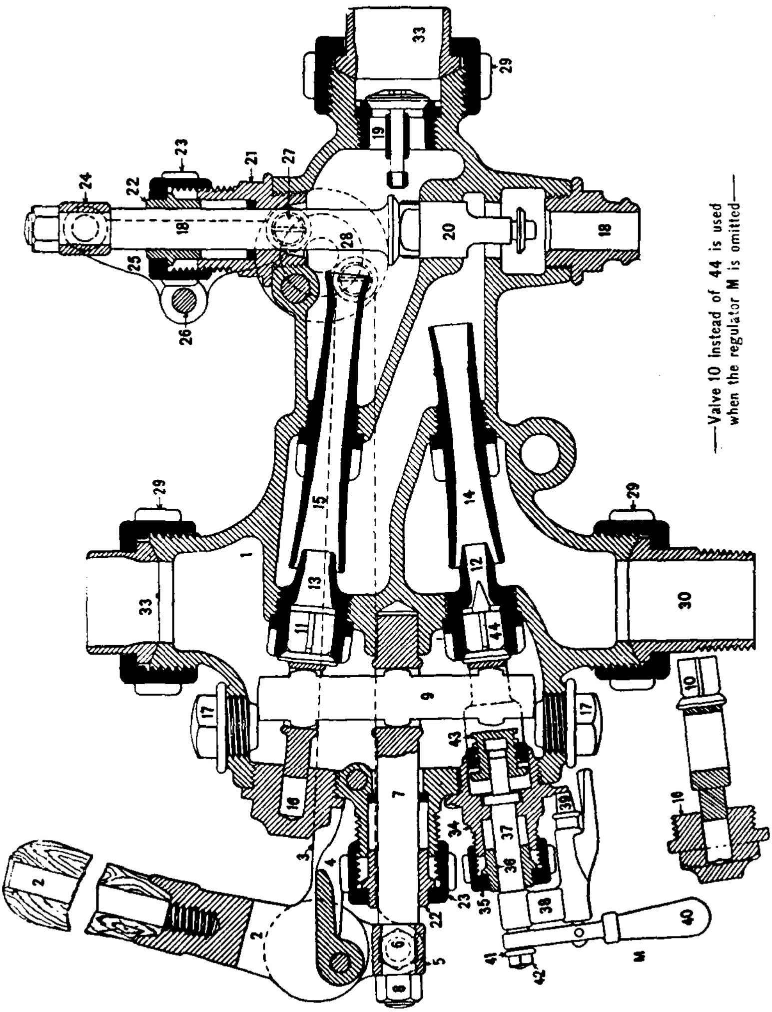


FIG. 19
THE KORTING COMPOUND INJECTOR

observing that compound injectors, in many cases, had no overflow chamber, but a valve in the delivery pipe was opened at starting, which acted as an overflow valve for the time being.

The compound injector was in use in America as early as 1874, the Hancock and Korting types being probably the first. A later pattern of the Korting compound injector is shown in Fig. 19, whose action was essentially as described above.

FEED HEATING

The suggestion had been made by Sharp that the feed water temperature could be raised by making the delivery jet from an ordinary injector pass through a divergent nozzle at the end of which it could be met by exhaust steam, which, on being condensed could be made to pass through a convergent and divergent tube into the boiler. This idea was reintroduced some twenty years ago by Gresham and Craven, using a heater (Fig. 20), which was mounted on the side of the boiler as much in the steam space as possible. The feed water from the injector was connected to the flange " A " and passed via the back pressure valve " B " to the heater nozzle " C," where it was given a sufficient velocity to cause a slight vacuum round the cone " D," which draws in steam, the steam, being immediately condensed, gave up its heat to the water. Similar action took place in the cone, resulting in the final mixture leaving this cone at almost steam temperature.

AMERICAN INJECTOR TYPES

As referred to in a previous section, Wm. Sellers & Co., of Philadelphia, introduced the injector into America. An early type of Sellers lifting injector is shown in Fig. 21*a*. Steam was admitted to the lifting nozzle by drawing the starting lever " 33 " about one inch, which did not withdraw the plug on the end of the spindle " 7 " from the central part of the steam nozzle " 3." Steam then passed through the small diagonally drilled holes and discharged by the outside nozzle through the upper part of the combining tube " 2 " and into the overflow chamber, lifting the overflow valve " 30 " and issuing from the overflow pipe " 29." When the water was lifted the starting lever was drawn back opening the forcing steam nozzle, and the full supply of steam discharged into the combining tube, forcing the water through the delivery tube into the boiler. At high steam pressures all injectors having side openings in the combining tube, produce a vacuum in the overflow chamber, and the improved type of this injector was utilised to draw an additional supply of water into the combining tube. By opening the inlet valve " 309 " the water was forced by the jet into the boiler, by which an increased capacity of 20 per cent. was claimed.

Figure 21*b* shows a " tell tale " device fitted to Sellers' injectors, to indicate to the enginemen if the injector is working properly without their having to look over the side of the cab. This detail is fitted to non-lifting injectors and consists of a cylinder containing a loosely

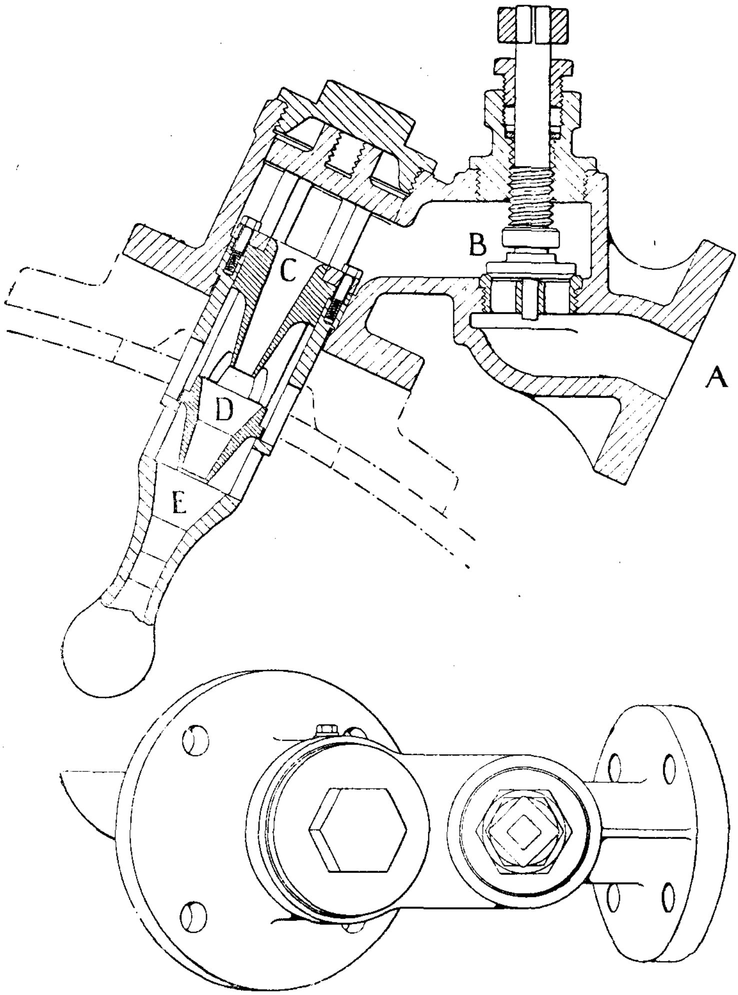


FIG. 20
THE GRESHAM AND CRAVEN FEED WATER HEATER

fitted piston with a projecting plug, visible when the injector is not feeding. It is connected to the overflow chamber by a ½ inch pipe. When the injector is feeding properly there is a partial vacuum in the overflow chamber, which lifts the piston of the indicator or tell tale, and the plug is drawn up. The moment the injector starts to waste, the plug drops, and the same action takes place if the injector "flies off," or blows back. The minimum capacity of the injector may be obtained by throttling until the plug moves rapidly up and down.

A Sellers' injector of the non-lifting type, but capable of working with high temperature feed water, is shown in Fig. 21*c*. This reduced the capacity of the injector by 20 per cent. with feed water at 100°F., 30 per cent. at 120°F. and 35 per cent. at 140°F. This injector is provided with a balanced inlet valve which gives an additional inflow of water to the combining cone increasing the capacity of the injector at high pressures.

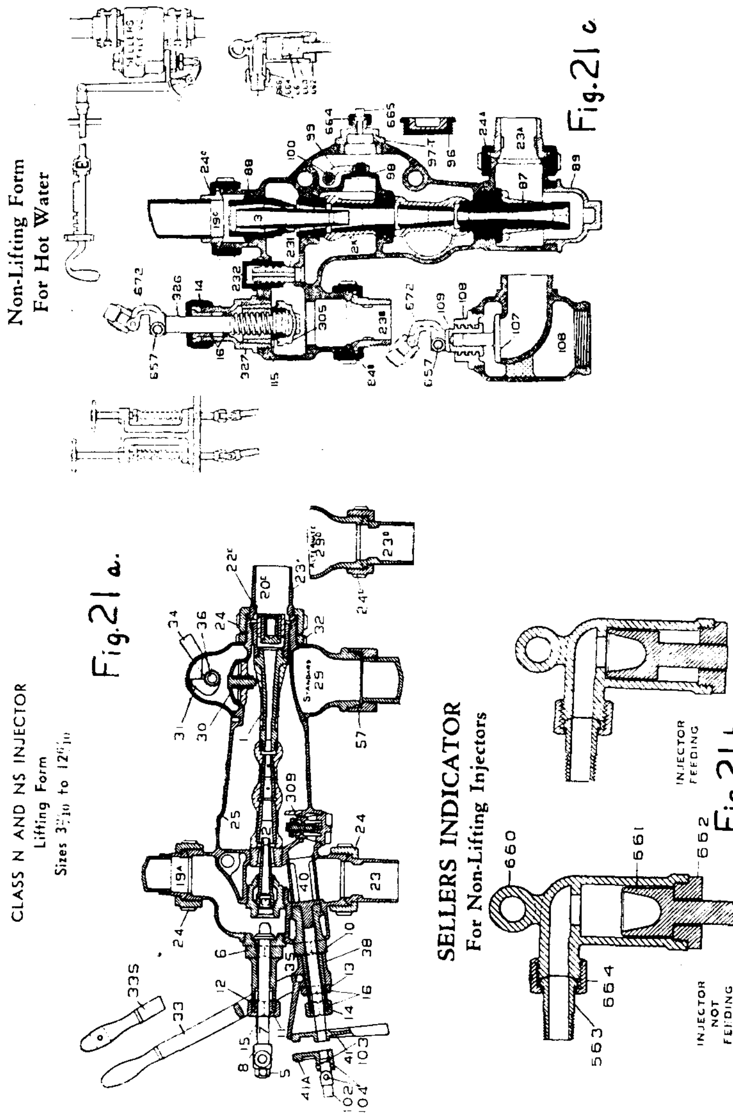


FIG. 21
SELLERS' SELF-ACTING INJECTORS

The Little Giant injector was introduced about 1870 (Fig. 22). It is of simple construction, its chief feature being the moving combining cone which the enginemen could adjust to work under different steam pressures.

The Nathan Manufacturing Co., of New York, manufacture the Monitor and Simplex types of injectors. The " R " type of injector

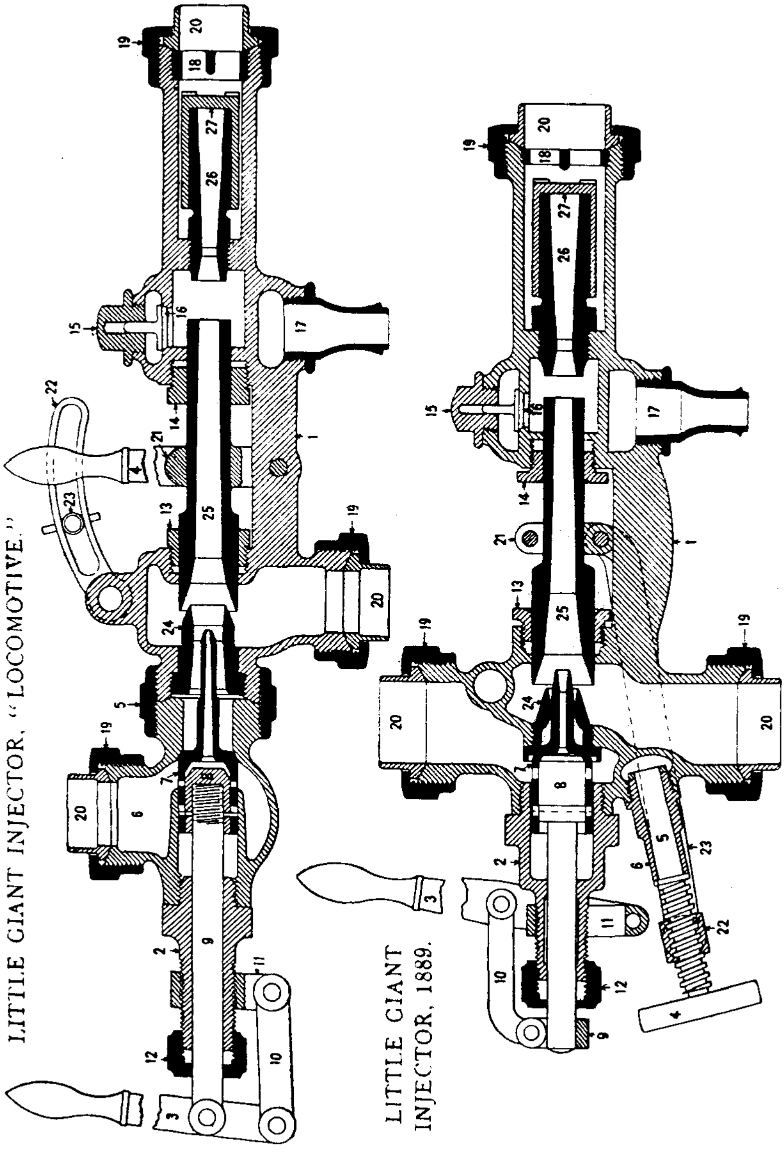
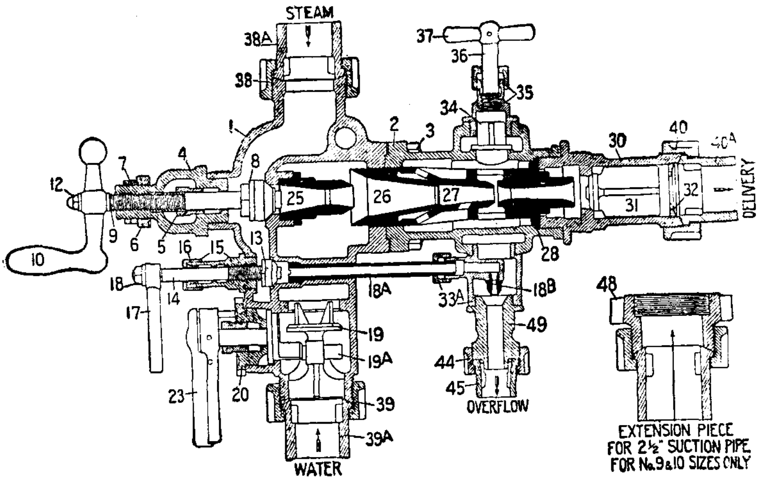


FIG. 22

THE MOVING COMBINING CONE " LITTLE GIANT " INJECTOR (CIRCA 1870)



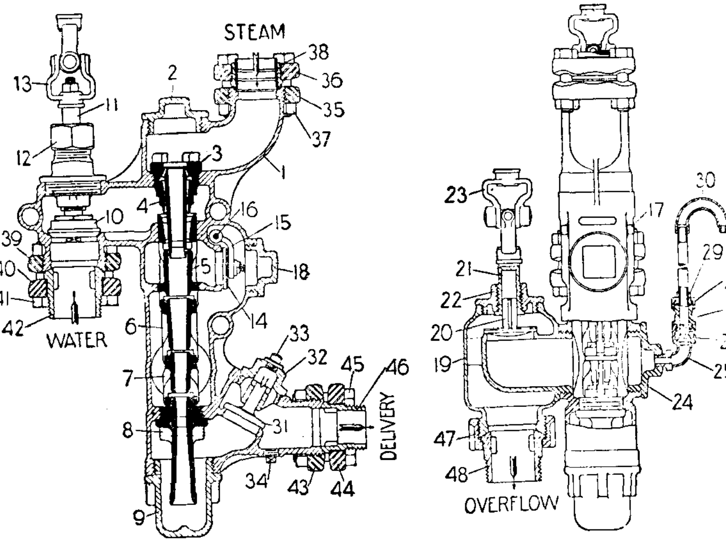


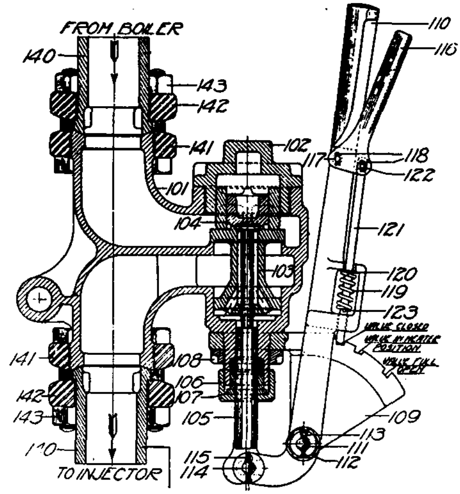
FIG. 23(*a*) (*Top*)

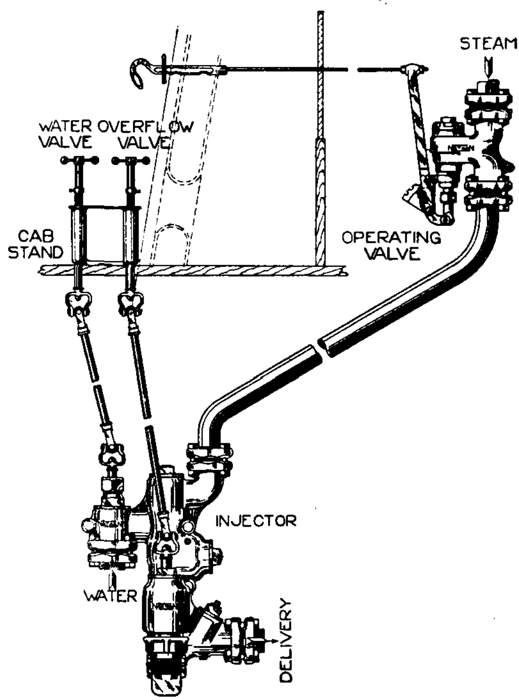
MONITOR TYPE " R " INJECTOR, NATHAN MANUFACTURING CO., NEW YORK

FIG. 23(*b*) (*Bottom*)

NON-LIFTING SIMPLEX TYPE INJECTOR, NATHAN MANUFACTURING CO., NEW YORK

BALANCED LEVER STARTING VALVE
TYPE 1921
FOR APPLICATION INSIDE OF CAB

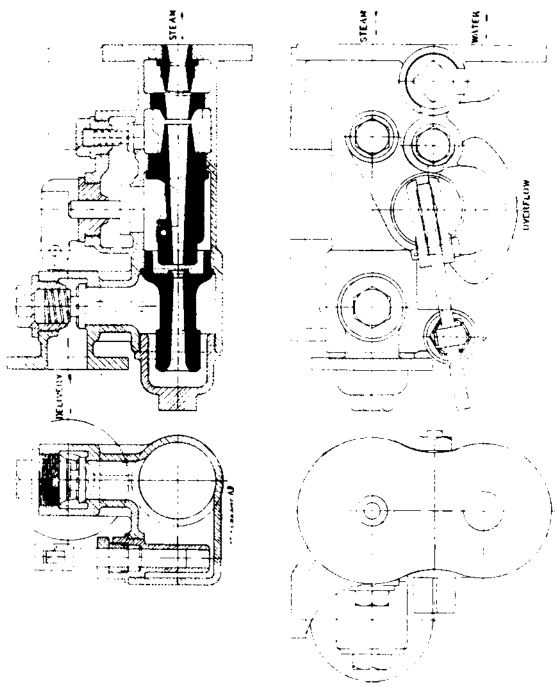




METHOD OF APPLICATION
FIGS. 23(*c*) (*top*) AND 23(*d*) (*bottom*)

(Fig. 23*a*) which dates in its original form from 1880 had relieving slots in the combining cone. The principal characteristic of this injector is the lifting jet, which, being independent and uninfluenced by any other part of the injector, enables it to make priming or starting reliable.

One form of Nathan Simplex injector was fitted to the 2-8-0 U.S.A. "austerity" locomotives which worked for a time in this country during the war years. This injector (Fig. 23*b*) was of the non-



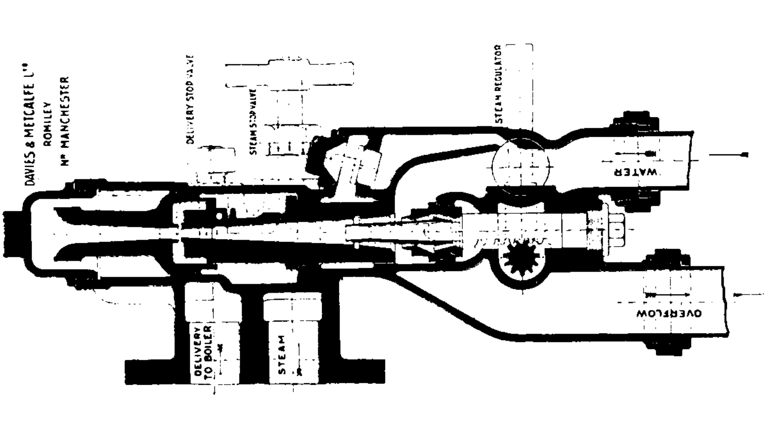


FIG. 24(*a*) (*left*) DAVIES AND METCALFE'S HORIZONTAL NON-LIFTING TYPE HOT WATER INJECTOR

FIG. 24(*b*) (*right*) METCALFE'S COMBINATION HOT WATER INJECTOR

lifting type and was fitted with a " tell tale " arrangement consisting of a check valve " 26 " placed in the tell tale elbow " 25 " and attached to the side cap " 24 " on the injector body on the opposite side of the overflow chamber. From this tell tale a small pipe was run up into the cab, terminating in an elbow nozzle within sight of the enginemen. When the injector " flies off " or is not working properly, part of the steam escaping through the overflow valve escapes through the tell tale check valve and a small stream issues through the tell tale nozzle, indicating the flying off of the injector.

The balanced lever starting valve or injector steam cock, common in the U.S.A., was used with this injector and is shown in section in Fig. 23*c*. The main valve was connected to a one piece casting with the balancing piston part. When the pilot valve is first opened by pulling out the lever slightly, steam is admitted underneath the balancing piston. The diameter of the piston, being only slightly less than that of the main valve, the pressure on top of the main valve is balanced to such a degree that the further movement of the lever will cause the main valve to lift from its seat easily and without any straining effect on the part of the enginemen. The injector lay-out and controls are shown in Fig. 23*d*.

HOT WATER INJECTORS

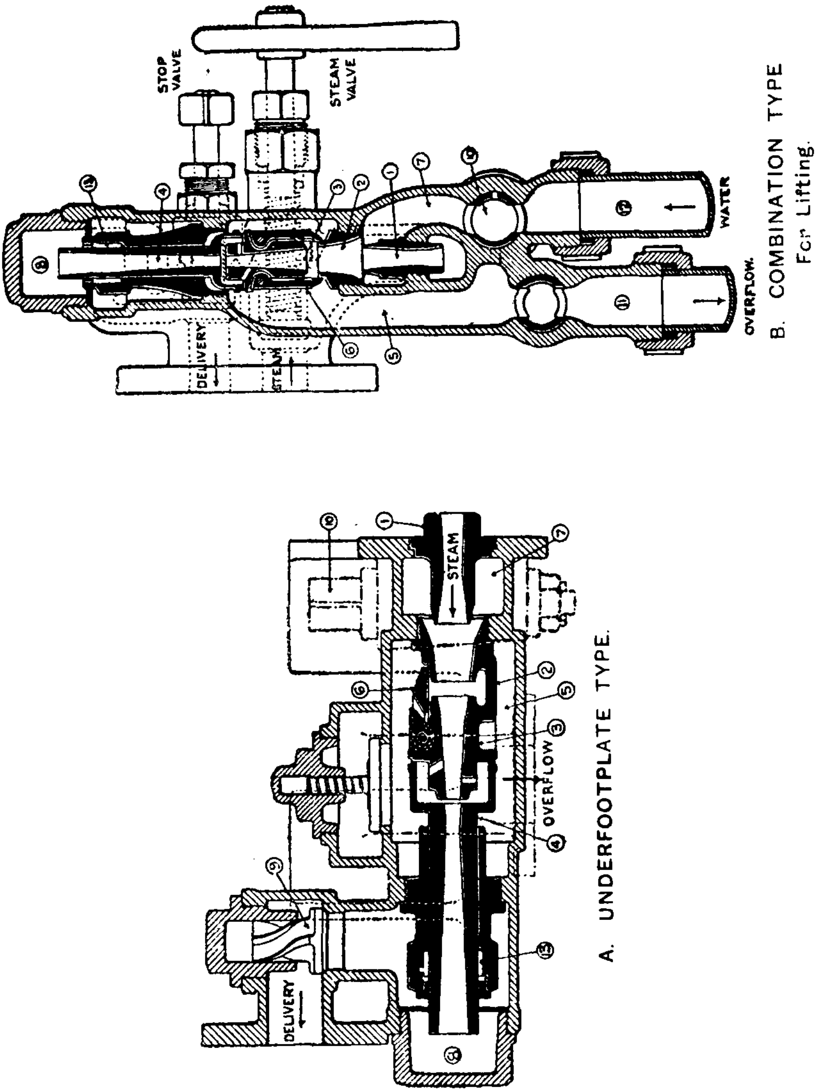
In this country, with the turn of the century, hot water injectors were more widely used. Fig. 24*a* shows a horizontal non-lifting type of Metcalfe's automatic hot water injector, fitted with a pressure controlled overflow valve, self-contained back-pressure valve and water cock. The various nozzles could be removed for cleaning and examination by unscrewing the end cap nut without breaking any pipe joints.

Metcalfe's patent combination hot water injector (Fig. 24*b*) is capable of working with feed water at any temperature up to 140°F. When the feed water is at a temperature between 130° and 140°F., the temperature of the water delivered to the boiler will be about 260°F. Special features of this injector are the pressure controlled overflow valve, the double steam cone, and the return of the rack and pinion controlled steam spindle. There is also a supplementary water passage connecting the water pipe with the first overflow chamber, and this is utilised to draw in an additional supply of water thereby increasing the delivery of the injector and strengthening the jet.

Gresham and Craven also manufactured a combination type of hot water injector (Fig. 25*a*) in which two side flap valves closed the gap between the lifting and combining cones. Once the water was lifted and when the injector started, the pressure created in the delivery chamber forced the sliding delivery cone down on its seat and completely sealed the jet from the atmosphere. Otherwise the water would be boiled off when using feed water at 130°F. Fig. 25*b* shows a non-lifting type of hot water injector by the same firm. This injector has one flap valve and one ordinary overflow valve with the moving delivery cone.

EXHAUST STEAM INJECTOR PRACTICE

Although exhaust steam injectors were manufactured by Messrs. Holden & Brooke, by Hopkinson's, and by Schaffer & Budenberg among others, it is with the Davies and Metcalfe exhaust steam injector that the locomotive is chiefly concerned. Early exhaust steam injector patents have already been described. Fig. 26 illustrates the evolution of the exhaust injector by this firm from 1877



FIGS. 25(a) AND 25(b)
GRESHAM'S PATENT HOT WATER INJECTORS

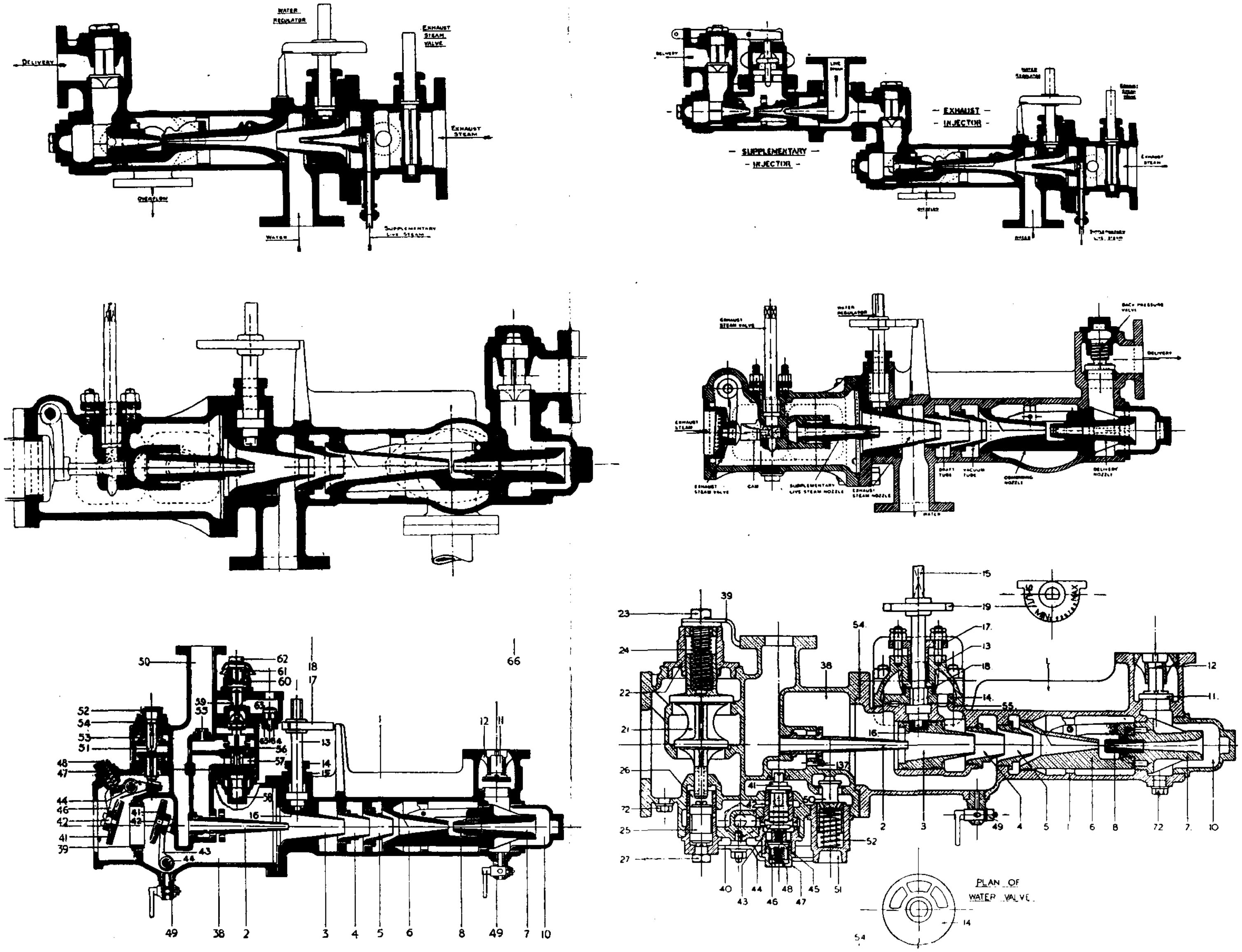


FIG. 26
EVOLUTION OF THE EXHAUST STEAM INJECTOR, 1877-1947

Top left "A" TYPE
Top right "B" TYPE
Centre left "D" TYPE
Centre right "F" TYPE
Bottom left "H" TYPE
Bottom right "J" TYPE

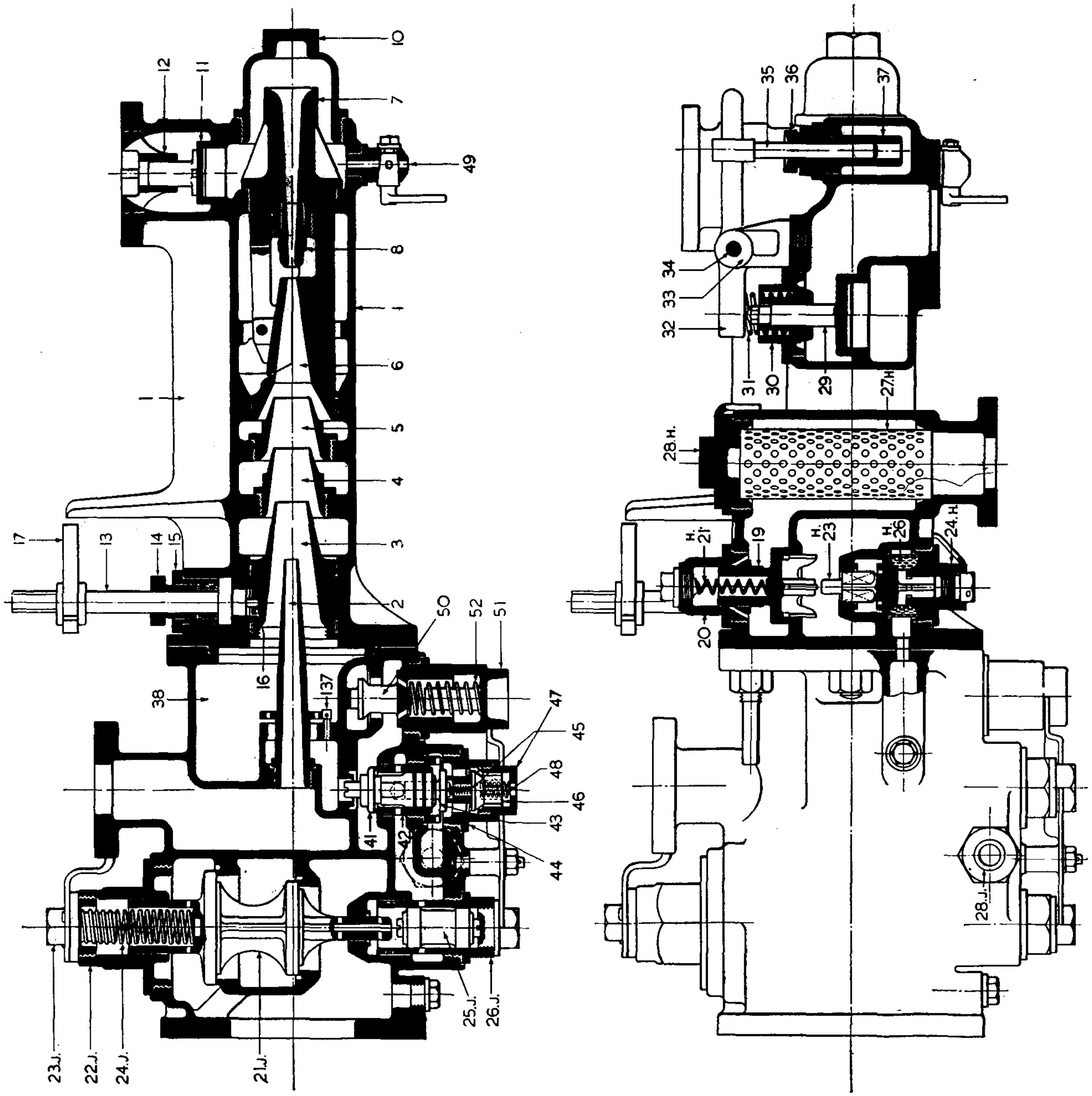


FIG. 27

SECTIONAL VIEWS OF THE "H/J" CLASS INJECTOR

Ref.	*Part*	
1	Injector Casing	
2	Supplementary Steam Cone	
3	Exhaust Steam Cone	
4	Draft Tube	
5	Vacuum Tube	
6	Combining Cone	
7	Delivery Cone	
8	Delivery Cone—Renewable End	
9	Delivery Cone—Setscrew	
10	Cone Cap Nut	
11	Back Pressure Valve	
12	Back Presssure Valve Guide	
13	Water Regulator Spindle	
14	Water Regulator Gland	
15	Water Regulator Stuffing Box	
16	Water Regulator Die	
17	Water Regulator Sector	
18	Water Regulator Sector Handle	
19	Water Valve	
20	Water Valve Guide Nut	
21H	Water Valve Spring	
21J	Exhaust Steam Valve	
22H	Water Valve Grinding Nut	
22J	Exhaust Steam Valve Cap Nut	
23J	Exhaust Steam Valve Grinding Nut	
23H	Water Control Piston Valve	
24J	Exhaust Steam Valve Spring	
24H	Water Control Piston Guide Nut	
25J	Exhaust Steam Valve Control Piston	
25H	Water Control Piston Grinding Nut	
26J	Control Piston Guide Nut	
26H	Water Control Piston Strainer	
27H	Feed Water Strainer	
27J	Control Piston Grinding Nut	
28H	Feed Water Strainer Cap Nut	
28J	Coupling Nut and Ring	
29	Overflow Valve	
30	Overflow Valve Guide Nut	
31	Overflow Valve Spring	
32	Overflow Control Lever	
33	Overflow Control Fulcrum	
34	Overflow Control Fulcrum Pin	
35	Overflow Control Piston	
36	Overflow Control Piston Gland	
37	Overflow Control Cylinder	
38	Exhaust Valve Casing	
39	Top Locking Plate	
40	Bottom Locking Plate	
41	Change-over Valve	
42	Change-over Valve Liner	
43	Automatic Check Valve	
44	Change-over Valve Cap Nut	
45	Automatic Check Valve Spring	
46	Drip Valve	
47	Drip Valve Cap Nut	
48	Drip Valve Spring	
49	Drain Cock	
50	Choke Valve (State Boiler Pressure)	
51	Choke Valve Guide Nut	
52	Choke Valve Spring	
53	Plug—Test	
58	Key for Item 42	
59	Guide Nut for Key	
66	Cone Box Key	
67	Grease Separator	
68	Grease Separator Drip Valve	
70	Locking Plate—Water Control Grinding Nut	
72	Drain Plug	
73	Warming Screw Spindle	
74	Spindle Guide Nut	
75	Spindle Guide Nut Setscrew	
76	Overflow Valve Guide	
82	Overflow Valve Casing	Used for Sizes No. 11-13 only
83	Overflow Valve Seating	
86	Locking Plate—F.W.S. Cap Nut	
137	Setscrew—Supp. Steam Cone	

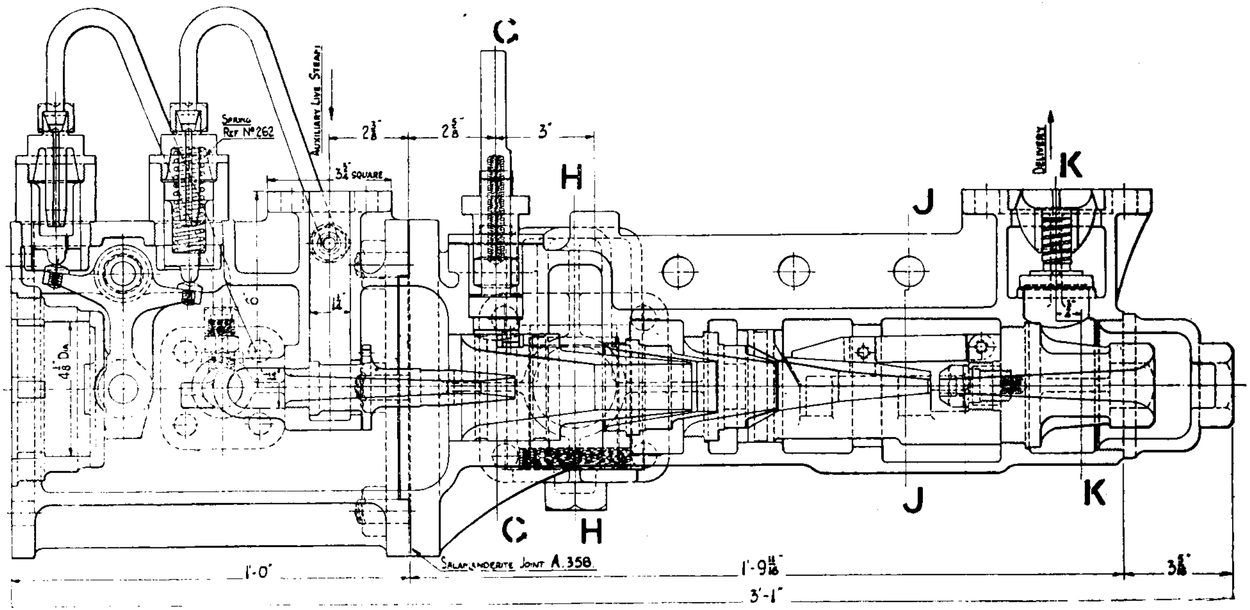


FIG. 28

ARRANGEMENT OF 12 M/M "H" TYPE EXHAUST INJECTOR,
WESTERN REGION, BRITISH RAILWAYS

till the present day in types " A " to " J." Type " C " was never introduced into service, being merely an experimental model. Type " A," of 1877, was designed and proved satisfactory for low pressure, but was not very suitable for locomotive work. It will be observed that the exhaust steam was aided by a small supply of supplementary steam and with this addition could deliver against a pressure of 150 lb./sq. in. Type " B," introduced in 1880, has already been mentioned. This was of the tandem or compound type and had some success in locomotive practice; the exhaust injector delivered into a supplementary live steam injector, in which higher feed water temperatures and pressures were obtained. This injector used a diaphragm controlled overflow valve. Later Messrs. Holden & Brooke made an injector on this principle in which Johnston's automatic water control was employed, the steam actuating the water control piston being connected to the steam chest of the engine. In 1906 the " D " type of exhaust steam injector made its appearance in which the two stage admission of steam was employed, this being the first type to use a draft tube in the nozzle system. The " D " injector was a big step forward and many locomotives used this injector both at home and abroad, including the " Great Bear " of the G.W. Railway. Following the " D " type came the " F " type about 1913 fitted with a pressure controlled overflow valve. The " G " type was next brought out but this was quickly superseded by the " H " type in 1922, with its automatic water supply and live and exhaust steam control. The " H " type gave great impetus to the use of the exhaust steam injector and it became almost standard throughout the world. The " J " type exhaust injector was brought out in 1941, and is similar to the " H " type so far as the cones are concerned, the difference being in the non-automatic water supply. The automatic change-over control and a double beat valve replaced the flap valves for exhaust steam control. About five years ago the H/J type of exhaust steam injector appeared, in which the improvements of the " J " type were combined with the automatically operated water valve as fitted to the " H " type. A sectional view of the H/J type with key to name of parts is shown in Fig. 27.

On the Western Region of the British Railways the " D " type of exhaust steam injector is standard except for the " King " class which has the " H " type. Both these types differ from the standard make of " D " and " H " exhaust steam injectors. The " D " injector on the Western Region has the exhaust steam valve operated automatically, and in the " H " type the automatic change over system and water valve is dispensed with and the arrangement shown in Fig. 28 is used. Here, separate steam cocks are used for the supplementary and auxiliary supply of steam to the injector, the only automatic feature being the opening and closing of the exhaust steam flap valve.

An American example of the exhaust steam injector is the " Elesco " type of the Superheater Co., of New York, which has been in use for the last 20 years. This injector (Fig. 29) is based on the Davies and Metcalfe principle but with a different change-over

system from live to exhaust steam working and vice versa. The change from live to exhaust steam working is accomplished by the exhaust steam pressure from the exhaust steam pipe operating on a diaphragm seating a pin valve and allowing live steam pressure to build up on the underside of a relay valve piston. The pressure moves the piston upwards and seats the relay valve on its upper seat.

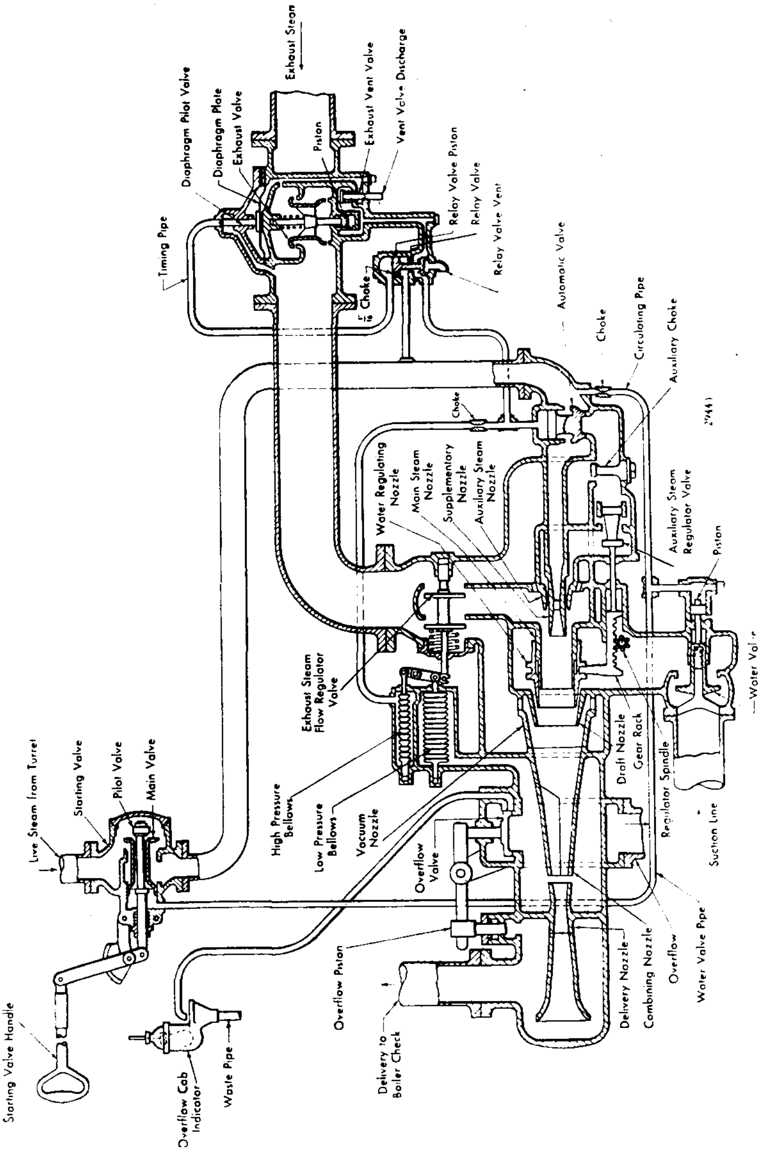


FIG. 29

"ELESCO" TYPE EXHAUST STEAM INJECTOR, SUPERHEATER CO., NEW YORK

This movement opens the port which admits live steam pressure on top of the automatic valve moving it from its upper to its lower seat, and shutting off the auxiliary steam. At the same time live steam pressure goes to the valve piston, forcing the exhaust valve to the open position, thus admitting exhaust steam to the injector.

A change from exhaust steam to live steam operation takes place when the exhaust steam pressure operating on the diaphragm drops below 1 lb./sq. in. pressure. The pin valve moves from its seat and live steam pressure on the underside of the relay valve piston is vented past the pin valve into the injector body. The relay piston and valve then moves to its lower position, releasing to the atmosphere the live steam pressure on the top of the automatic valve which moves from its lower to its upper seat admitting auxiliary steam to the injector. At the same time the spring on the exhaust valve closes the valve.

Instead of an overflow cab indicator previously described, the Elesco exhaust steam injector makes use of a dial injector gauge. This gauge has three pointers, one of which is moved from the outside like the pointer of a barometer.

(1) Black pointer shows exhaust pressure in the injector body when working on exhaust steam, and auxiliary pressure at the same point when working as a live steam injector.

(2) Red pointer shows overflow pressure in injector.

(3) Brass pointer is set at the pressure which, when reached by the red hand, indicates spilling at the overflow. Since the pressure at which spilling occurs varies with the different boiler pressures, this hand is set on the engine while full working pressure is on boiler.

The change-over valve on the Continental Friedmann exhaust-steam injector is separate from the injector, and usually placed in the engine cab. This was illustrated and described in L. J. Kastner's Paper, No. 396, on " Exhaust Steam Injectors," September 1938.

MODERN INJECTOR TYPES

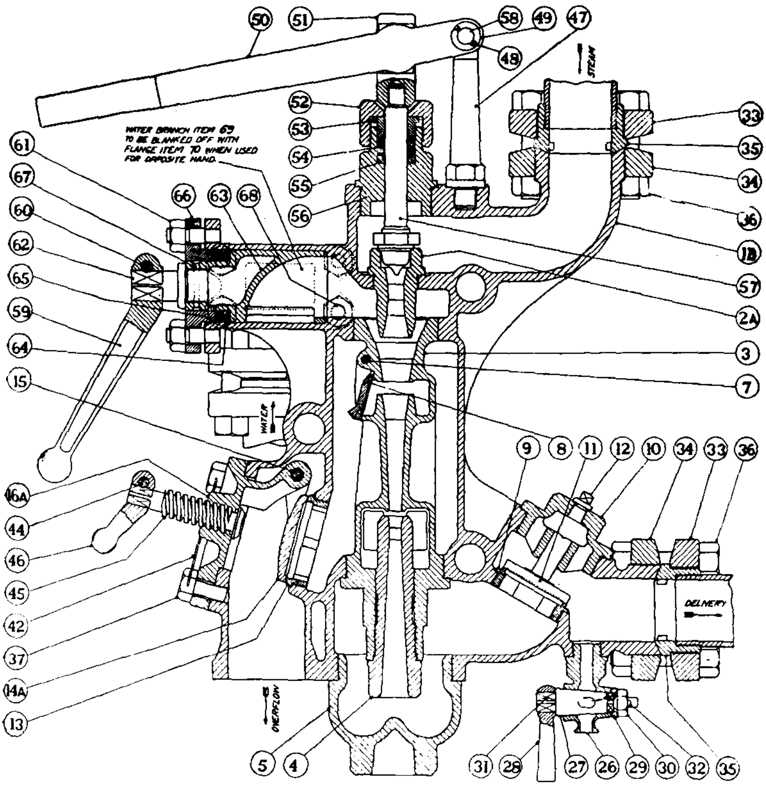
Modern live steam injectors, as used in this country, are usually of the flood type with gradual replacement of injectors using sliding combining cones or split combining cones. The latest class of injector produced by Gresham & Craven Ltd. is their " R " type series made in three forms:—

Type " RCW "—Flood injectors to deal with water up to 110°F.

Type " RHW "—Hot water flood injector to deal with water up to 140°F.

Type " RL "—Combination lifting injector for water up to 100°F.

These injectors with different types of cones are shown in Figs. 30*a* and 30*b* and are arranged to work in a vertical position only. The cones for the RCW and RL types are the cold water or standard cones and they can be removed without breaking a steam or water joint, by



Section through RL Injector

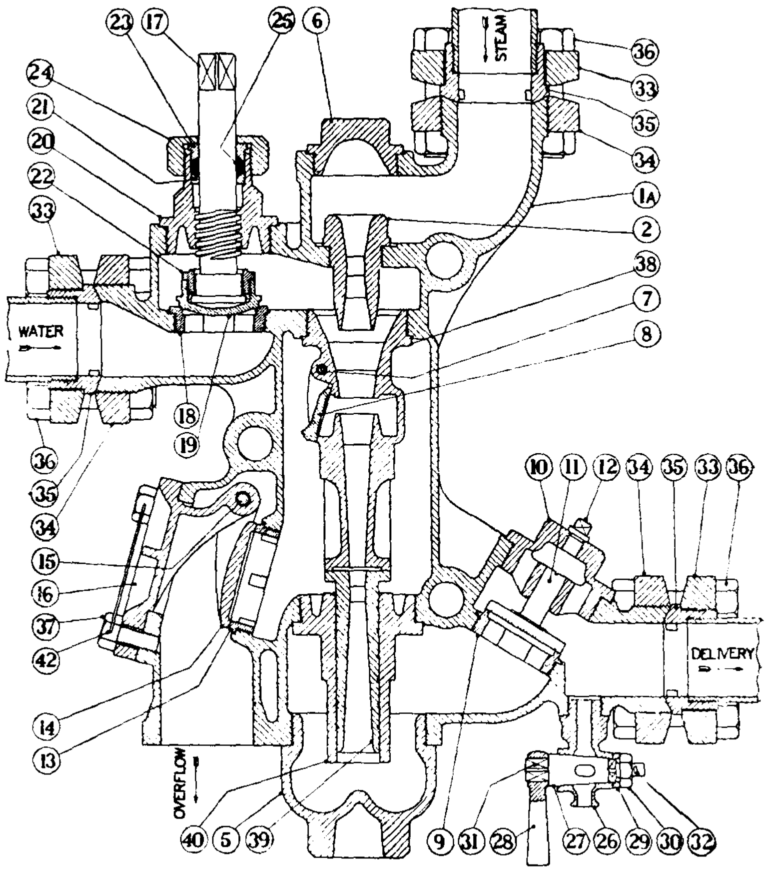
FIG. 30(*a*)

GRESHAM'S CLASS " R " LOCOMOTIVE INJECTOR TYPE RL

taking off the respective end caps, while the water, combining and delivery cones are in one piece assembly facilitating replacements.

A sliding delivery cone is provide in the RHW hot water injector to close the gap between the delivery and combining cones. No packing is used but instead a labyrinth type of fine limit sliding fit is effective in sealing this cone without restricting its movement. In each of the three types a flap valve is used for the auxiliary overflow instead of a sliding combining cone. The figures show sectional views of these three types of injectors, from which it will be observed that the combination lifting type RL is fitted with a lever operated steam valve.

Davies & Metcalfe Ltd. produced their " Monitor " injectors early in the war years, employing the twin jet steam cone and gap type combining cone. The delivery cone has a renewable end and, if required, a pressure controlled overflow valve can be fitted. Figs.



Section through RHW Injector

FIG. 30(*b*)

GRESHAM'S CLASS " R " LOCOMOTIVE INJECTOR TYPE RHW

31*a*, 31*b* and 31*c* show the " M " type cones in which it will be seen that the inner steam cone is screwed into the injector body and its bore admits a secondary or forcing jet of steam. The outer steam cone which screws on to the inner cone forms an annular passage between the two cones. The steam admitted through this passage is known as the primary or annular steam jet. The combining cone has slots or gaps in its length in the walls of the cone, and gives access from the cone itself into the overflow chamber. When starting the injector, the mixture of steam and water entering the combining cone escapes freely through these slots into the overflow chamber, until the jet is established and the injector starts to work, when the fast moving jet of steam and water jumps these gaps without waste.

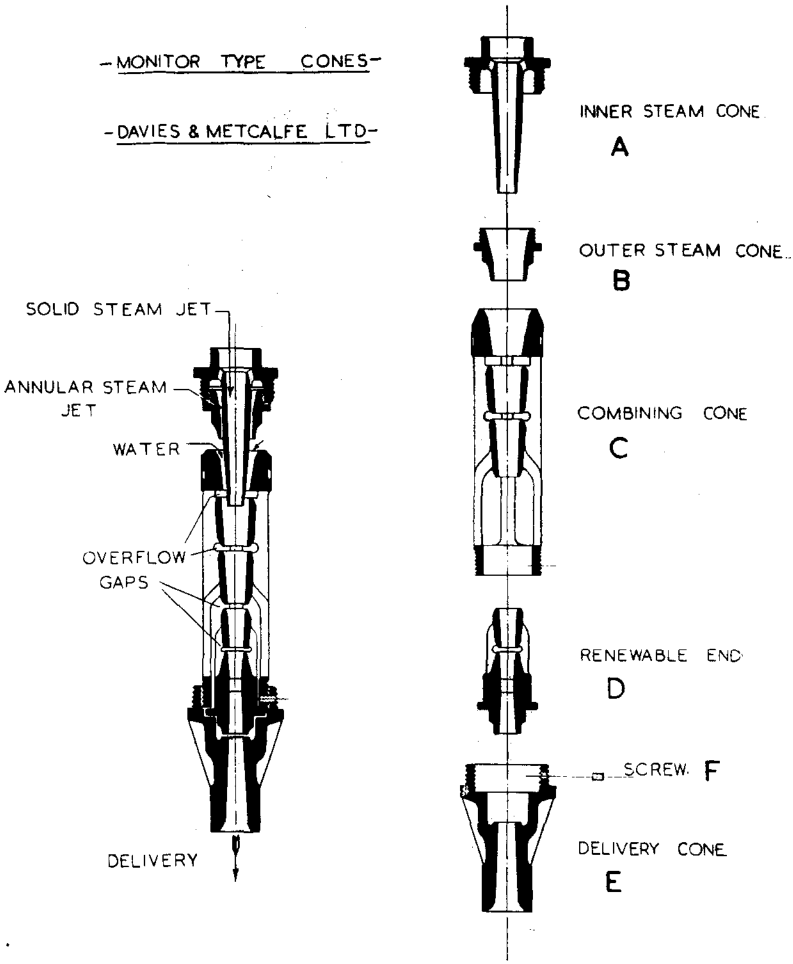


FIG. 31(*a*)
MONITOR TYPE CONES

TABLE OF PIPE SIZES AND CAPACITIES

Size of injector	*Capacity gallons per hour*	*Min. bore steam, water and delivery*	*Min. bore of overflow*
4	300	1″	1¼″
5	500	1¼″	1½″
6	750	1¼″	1½″
7	1,100	1¼″	1½″
8	1,450	1½″	1½″
9	1,850	1½″	1½″
10	2,300	1¾″	2″
11	2,850	2″	2″
12	3,500	2¼″	2½″
13	4,200	2¼″	2½″

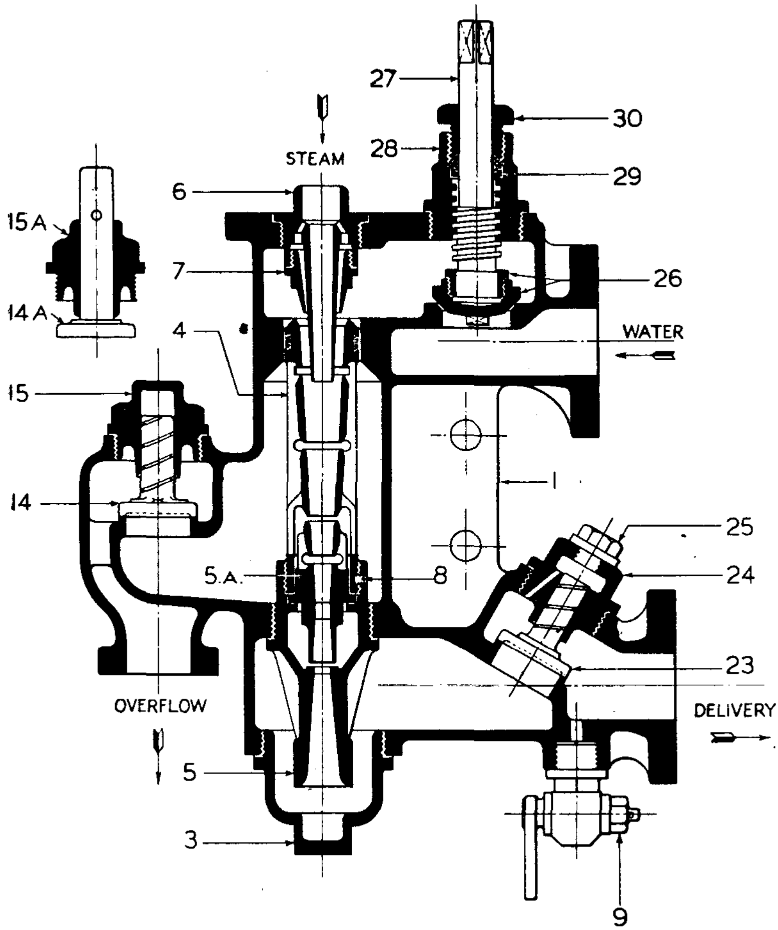


FIG. 31(*b*)

NON-LIFTING TYPE D.M. INJECTOR

The delivery cone renewable end consists of a small unit which forms the small ends of both combining and delivery cones, together with the overflow gap between the cones. The delivery cone is screwed on to the combining cone forming one unit and retains the renewable end by a flange on the latter. The combining and delivery cones can therefore be withdrawn from the injector body by simply unscrewing the delivery cone.

This class of injector is made in types "D," "OM" and "LM" and an austerity type, all non-lifting. There is also a lifting type which can be fixed in the locomotive cab, and the steam valve

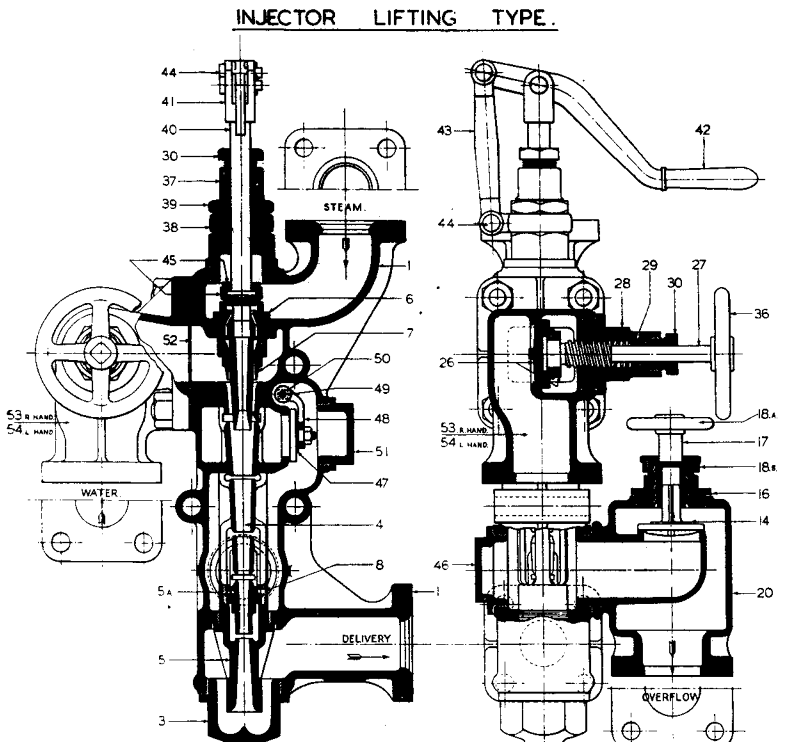


FIG. 31(*c*)

of which is controlled by a lever. The first movement of this lever opens the steam to the annular priming or lifting jet creating a strong vacuum which quickly causes the injector to be primed. When the water appears at the overflow the lever is moved to the full open position and the injector will immediately commence to feed the boiler.

CLACK OR CHECK VALVES

Only a few remarks can be made on clack, check or discharge valves and the position where the feed water is put into the boiler. For years the standard practice was to locate the clack box on the side of the boiler barrel, rather nearer to the smokebox than to the firebox, a position occupied by the feed pump of the early locomotive with vertical cylinders.

The " Rocket " with its inclined cylinders and crosshead pump had its clack on the left side of the firebox. Clack valves, up to recent times consisted of ball valves, single or double mitre valves or flat valves. In dealing with locomotives built from the 'sixties to the present day the Author has seen the feed water discharged into

the boiler under the barrel, on the boiler throat plate, on the boiler back plate, on the boiler back plate at the foundation ring, on the smokebox tube plate and in varying positions on the side of the boiler barrel.

When the clack box is situated on the boiler back plate it is usually combined with the injector steam cock, which is supplied with steam from an internal steam pipe. Top feed arrangements were used in varying types by all British railway systems before Nationalisation as shown in Fig. 32. The water was led into the boiler from the top or side of a small dome and passed over different forms of sludge trays or other devices. The " austerity " locomotives

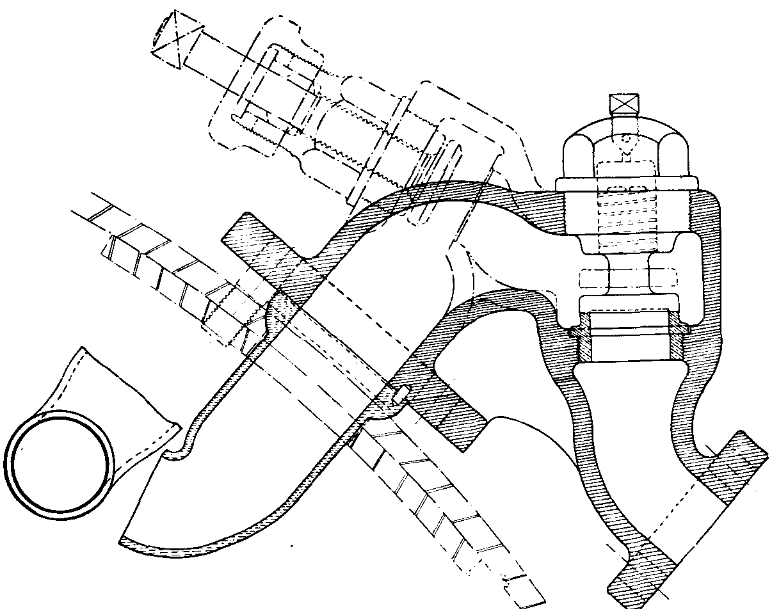


FIG. 33
CLACK BOX
MERCHANT NAVY AND WEST COUNTRY CLASS

built during the war years have the clack valves placed on top of the boiler barrel near its front end, these valves have a screw down valve for each clack. The Merchant Navy and West Country Class locomotives of the Southern Region have the two clack valves situated together on the right top side of the boiler barrel near the smokebox tubeplate. Fig. 33 shows this valve, which on the West Country Class, originally had a screw down stop valve as shown chain dotted. The outlet nozzles are made of gun metal alloy and have their outlets facing towards the smokebox tubeplate. The latest form of top feed valves and deflector plates

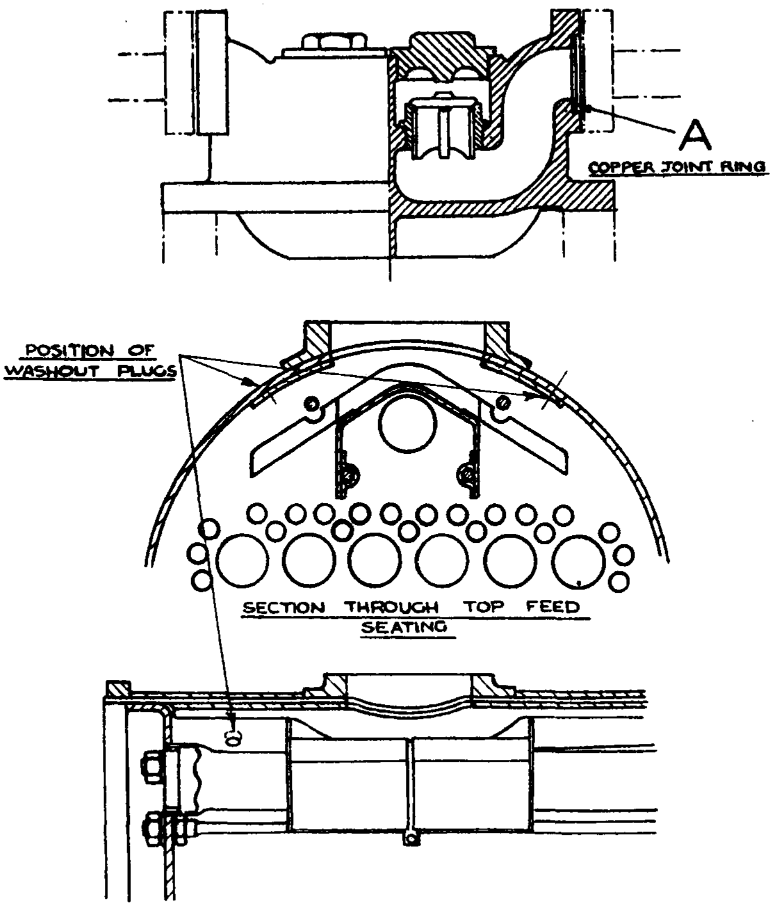


FIG. 34(*a*) (*top*)
LATEST TYPE TOP FEED CLACK BOX, L.M. REGION, BRITISH RAILWAYS

FIG. 34(*b*) (*bottom*)
LATEST FORM OF DEFLECTOR PLATES FOR TOP FEED APPARATUS, L.M. REGION, BRITISH RAILWAYS

(which displaced sludge trays) used on the London Midland Region of British Railways is shown in Figs. 34*a* and 34*b*, these also being placed on the top of the boiler barrel.

In the discussion on Mr. Churchward's Paper on "Large Locomotive Boilers" to the Institution of Mechanical Engineers in 1906, Mr. Vaughan Pendred remarked that the best possible place to put the feed water into the boiler is the steam space at the smokebox end. During the same discussion Mr. James Stirling stated that

after trying feed water inlets in almost every position he considered that the old fashioned place on the side of the boiler was as good as any. Top feed arrangements were used in Germany from 1863 but were later discarded and although this type of feed inlet will probably be standard on British Railways it has the disadvantage of the length of delivery pipe required and the difficulty of dismantling for repair.

The controversy is always with us as to the question of fitting screw down stop valves on the boiler side of the clack box. The Author favours the fitting of these valves after considerable experience of both types. The main objection to the use of the stop valve is its tendency to seize due to infrequent use. With the modern standard examination of locomotives, however, the seizing of stop valves need not be experienced. It is a great advantage to be able to examine a clack valve when the engine is in steam and by screwing down the stop valve, failures from leaking or stuck clacks can be eliminated.

CLASSIFICATION OF INJECTORS

Definition:

The injector has been defined as a jet apparatus in which a gaseous jet impinges on and is condensed by a fluid mass whose final kinetic energy exceeds that of a jet of similar form and density discharging under the initial pressure of the motive jet.

Non-Lifting Injector:

Non-lifting or flood injectors cannot lift water, and are situated below tender or tank level, the water flowing by gravity into the injector.

Lifting Injector:

Lifting injectors both raise the water and force it into the boiler. This type of injector is placed on boiler back plate or in the engine cab, just above the highest level of the water in the tank.

Single Jet Injector:

The ordinary type of injector in which a single set of combining and delivery cones is employed and can be either self-adjusting or automatic or both.

Double Jet or Compound Injector:

This type of injector has two sets of cones. The first or lifting set receives the feed water and delivers it into the second or forcing set of cones, where it receives sufficient impulse to enter the boiler at a high temperature.

Automatic or Restarting Injector:

An injector that is able to re-establish automatically (usually by a supplementary overflow) the continuity of the jet, after an interruption in the steam or water supply.

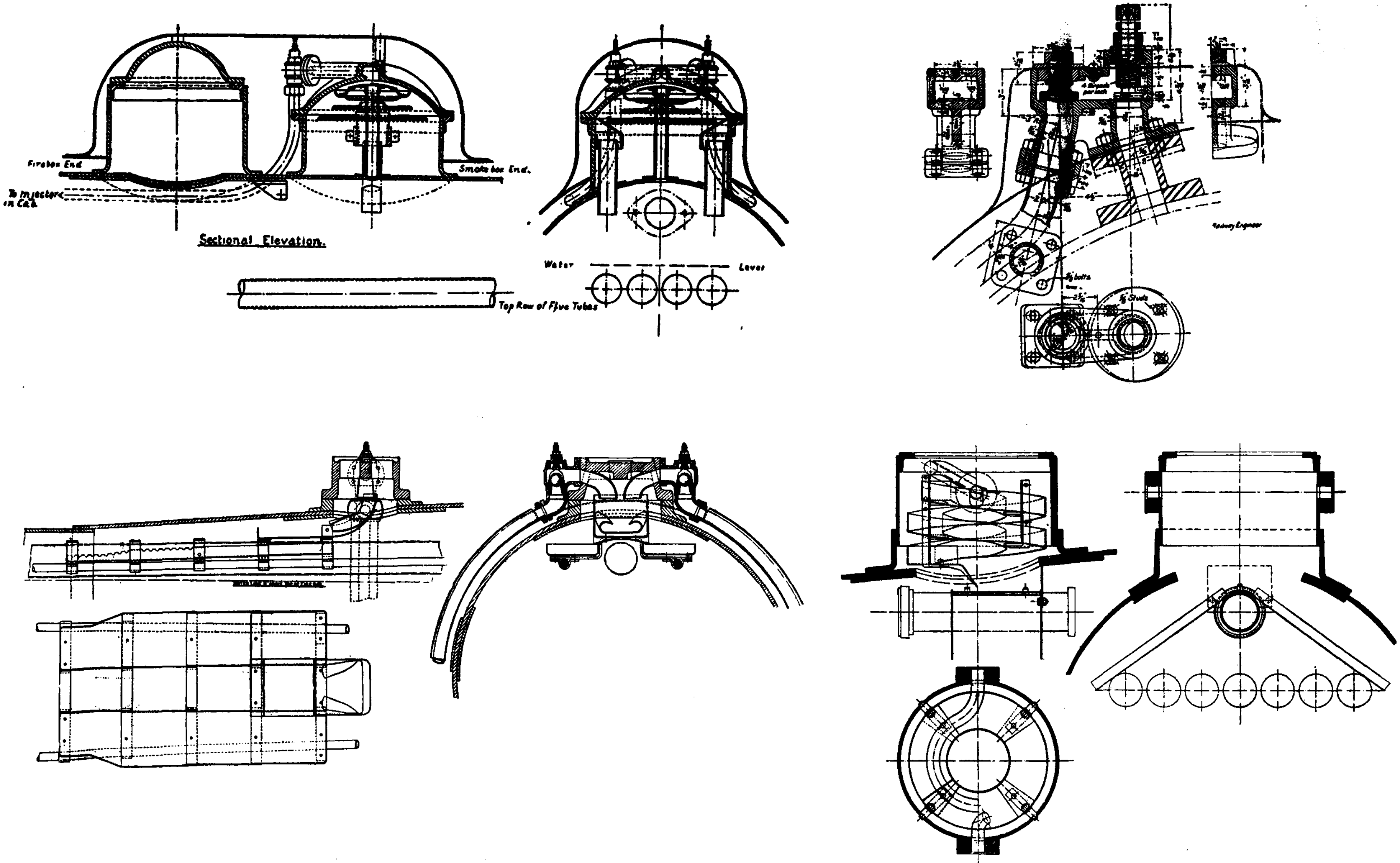


Fig. 32

Top left Gresley's top feed apparatus
Bottom left Churchward's top feed apparatus
Top right Top feed valve, ex-L.N.E.R. (G.C. Section)
Bottom right Maunsell's top feed apparatus

Self Adjusting Injector:

This term is applied to an injector in which the water supply to the boiler is automatically adjusted to suit the steam supply without waste, usually accomplished by the use of the double type of steam cone.

Hot Water Injector:

An injector designed to operate with feed water up to about 150°F., provision being made to shut off the injector cones from the atmosphere once the injector has started to work.

Exhaust Steam Injector:

An injector using steam that has performed a previous duty, usually supplemented by a small supply of live steam. It can be operated as a live steam injector by a supply of auxiliary live steam to take the place of the exhaust steam and this auxiliary live steam can be supplied automatically or otherwise. The exhaust steam injector is of the non-lifting type and is somewhat larger than a live steam injector of the same capacity.

Closed Overflow Injector:

A type of injector that can only start by means of an opening placed beyond the delivery cone, which opening must be closed to direct the jet into the boiler.

Open Overflow Injector

Ordinary injectors are in this category, when there are one or more openings in the combining cone, opening into one or more overflow chambers, which may be closed against the admission of air by use of check valves opening outward.

Note—The Primary Overflow is a chamber placed before the minimum diameter of the delivery cone giving free outlet for the water and steam during the operation of starting the injector. The supplementary or secondary overflow, used on all automatic injectors, is placed nearest to the steam nozzle and is made of sufficient area to allow for the free emission of the full discharge of the steam nozzle till the jet is formed. The secondary overflow is provided by either a sliding or flap combining cone or by a slotted combining cone or by used of a flap valve when the divided combining cone is used.

CONCLUSION

The foregoing survey indicates that, after almost a century of injector working, this instrument is unrivalled at the present time on British Railways. At present there are fewer water feed pumps used than at any time in the history of the locomotive. Since 1860 each decade has seen the revival of the use of feed pumps in various forms and during the first half of this century feed pumps have been

used with many arrangements of feed water heating. These have had quite a short life, and with the advent of improved types of exhaust steam injectors during the last thirty years, pumps and feed water heating have held no permanent position in British locomotive practice.

From the early 'twenties the use of the exhaust steam injector on main line locomotives has been almost standard practice and the resulting increase in maintenance trouble at motive power depots is beyond dispute. One cannot but compare the almost trouble-free first quarter of the present century with the second quarter during which the care and maintenance of the automatic change-over exhaust steam injector has proved unduly expensive. This state of affairs has often led to the question of whether the admitted advantages of this type of injector as a feed water heater are sufficient to compensate for the increased maintenance and lowering of locomotive availability. Indeed, during the late war the blanking-off of the auxiliary steam pipe from the locomotive steam chest to the injector, making it operate only as a live steam injector, was sanctioned in one railway group when trouble was experienced. Later, however, this instruction was withdrawn after the question of the exhaust steam injectors' fuel saving ability had been raised in higher circles.

As previously stated, the exhaust steam injectors used on the Great Western Railway employ two separate injector steam cocks in place of the automatic change-over apparatus and this calls for increased attention from the fireman in the interests of reliability. During 1945 the Southern Railway decided that no more exhaust steam injectors would be purchased, and that this type of injector would be gradually replaced by live steam injectors of the Monitor type. The present policy of British Railways is for all locomotives of a power classification of four or less to be fitted with two live steam injectors and for locomotives of classification of five or more to have one live steam injector and one exhaust steam injector in each case, both injectors being capable of operation from the right (fireman's) side of the locomotive. The Author's practical experience however of the reliability and upkeep of the intensively operated "common user" locomotive working 12 to 16 days between shed days has led him to hold the view that two modern live steam injectors invariably prove more reliable and, in the long run, more economical.

It is the Author's opinion that the design of the modern steam locomotive should include the repositioning of the injectors. Most injectors fitted below the footplate, outside the main frames, are in the air stream which is formed by the movement of the locomotive and are subject to atmospheric conditions which render heat losses considerable, while there is the disadvantage of the long delivery pipes necessary. In this respect there is still something to be said in favour of injectors of the combination type or for the positioning of injectors directly under the footplate as used by Webb on the L. & N.W. Railway, provided that facility for examination and repair be made from the engine footplate.

ACKNOWLEDGMENT

The Author wishes to express his thanks for information received from the following: British Railways Executive, Gresham & Craven Ltd., Manchester, Davies & Metcalfe Ltd., Manchester, The Superheater Co. Ltd., London, Green & Boulding Ltd., London, Locomotive Publishing Co., London, Nathan Manufacturing Co., New York and Wm. Sellers & Co., Philadelphia.

DISCUSSION

The **President** said they owed a great debt to the Author from the historical point of view, for putting together so ably all the information that was available on the development of the injector. The amount of work put into the Paper far surpassed the time taken to read it, and it was a matter for congratulation that the Institution now had so complete a record of what had been done with regard to this most important fitting.

With regard to the Author's suggestion about the exhaust steam injector, he would be disappointed to know that it was proposed to go on with them. The defeatist attitude that because they had been difficult to maintain in the past they would always be difficult to maintain was not accepted. At the same time, a miner earned far more money than a fitter and coal, apart from being expensive, became even more scarce as time went on.

Mr. J. N. Gresham (M.) said he had very little to add to Mr. Shield's excellent historical Paper. It contained one mistake, he thought: the statement that the original Giffard injector would only lift 5 to 6 feet. Those made by Sharp & Stewart after they had taken over the Giffard patents in 1861 lifted 19½ feet. He had records of them in some of his grandfather's books, which he had brought with him. They were certainly capable of lifting a great deal more than 5 to 6 feet, and he felt sure the original Giffard did better than that.

The tale told about the coming of the first injector was the one he had always heard from his grandfather who was at that time a craftsman at the Sharp & Stewart locomotive works in Manchester. It was to his grandfather that Mr. Robinson had given this new box of tricks that had arrived from Paris without any instructions, and by great good fortune he had coupled the pipes up in the right way. To the astonishment of everybody the thing worked.

Looking back on the history of these injectors, one point struck him which was not brought out in the Paper. The injector arrived in 1858 or 1859, but at that time the convergent nozzle was used. Steam was still regarded as a liquid, and the first attempts at a divergent nozzle were not made until about 1877. It was not until about 1884, with full recognition of the fact that steam was a gas, that the divergent nozzle was employed generally in injector practice.

If he might be permitted to introduce a little levity into the serious business of the evening, he would like to quote two small passages. Mr. John Robinson, who was then the head of Sharp & Stewart, read a paper to the Institution of Mechanical Engineers about this new instrument which had been obtained from France in 1860. He concluded his paper by saying:

> It has not been attempted to give any calculation of the power obtained by the injector and, indeed, the writer has been discouraged from attempting this by the opinion of an eminent hydraulic engineer that the injector is a valuable application of a force which very few persons understand and which has never been explained in books: that it was found possible with a steam of 24 lb. pressure to inject water into a boiler of 48 lb. It is felt it would be premature to bring forward conclusions brought on the basis of experiments so hastily made which require consideration and discussion before any safe conclusions can be arrived at."

The theory did not seem to have developed very fast, because there was the following entry in his grandfather's notebook, the date being 1863 (and it must be remembered these were Manchester people):

> " H. Chapman's theory of the working of an injector: It is like a bale of cotton weighing, say, 200 lb., going at a velocity of, say, 600 miles per hour, imparting its velocity to a piece of iron weighing 100 lb. and giving the iron all its velocity. Therefore there is no creation of power, as some wrongly suppose, merely a concentration of it. The working of the injector may be illustrated in this manner. If we suppose a bale of cotton weighing 200 lb. thrown against a wall or a door, its moving force being so diffused it would stop harmlessly. But if it be supposed that this same bale of cotton were imparting the whole of its velocity (of course less friction) to a piece of iron of half its weight, then the iron being a much denser object than the cotton, its penetrating force would be much greater. Therefore it would pass through the wall or door. This theory explains why the injector will not work with hot water, which no other theory clearly does. Warm water being less dense it reduces the density of the iron too near to that of the cotton. The injector stops altogether when they come too near the steam."

In 1864 Marshall published a theory which corresponded with the modern theory of injector practice.

Many famous names had been connected with the early development of the injector—Gresham, Bousfield, Clark, Fletcher and Bower, Andrew Barclay, Robinson, Morton Fairlie, Dugald Drummond—all these people had attempted to improve the Giffard injector and many of the improvements had come to Sharp & Stewart on a trial basis to see how they compared with the original Giffard. He would not like to give some of the comments that appeared in his grandfather's notebook, but the original Giffard patents were never improved upon for that particular style of injector.

Mr. E. S. Cox (M.) said the opportunity had been taken, in connection with the design of the new British locomotives, to put on the test plant all the injectors commonly available for locomotive work in this country. He did not propose at this stage to indicate which had turned out to be the best, but consideration of the results raised one or two points of interest in connection with the Paper.

One of the most striking results was that although the injectors tested, whether of railway company or private firm design, all represented the best practice available to their protagonists, there were the most surprising differences in the kind of performance which was produced.

The test had taken the form of relating the output of the injector in lb. of steam per hour, or gallons per minute, against steam pressure in lb. per square inch. See Fig. 35. The performance of the best injector for British railway conditions was shown on the

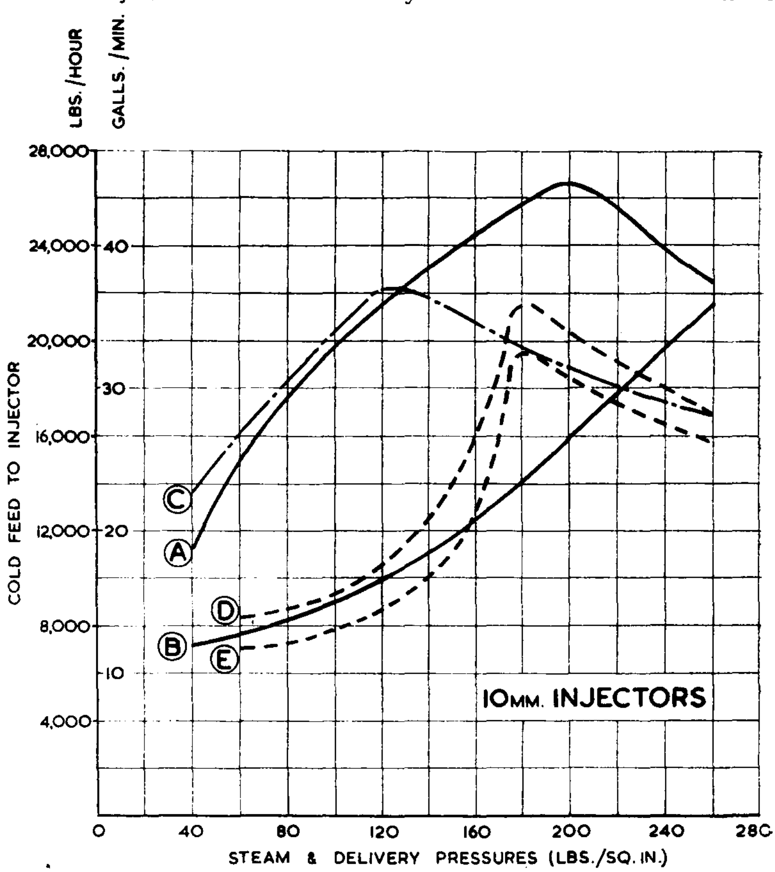


FIG. 35

CURVES RELATING INJECTOR OUTPUT WITH STEAM PRESSURE

diagram and could be indicated, first of all, by a line A representing maximum delivery at any given boiler pressure and secondly by a line B representing the minimum feed which the injector would maintain constantly with the steam valve full open and with a variation in the water feed valve. The difference between the two lines represented a range of performance of the injector which was thought to be a very valuable feature. Although it represented the kind of performance given by the best injector, however, it was of interest that the maximum output and range did not occur at maximum boiler pressure but at approximately 200 lb.

At 250 lb. pressure this injector—which was designed, of course, for a range of pressures: one did not aim to produce a different injector for each different working pressure—had a somewhat reduced range. The maximum range was about 11,000 and it was reduced to something like 300 with reduction in maximum performance, so that in spite of a hundred years' development there did seem to be some further work to be done. It was clear that if it were not flying in the face of Nature in some way, a performance which would more nearly give maximum range and output at maximum working pressure would be more valuable for general locomotive purposes.

Some of the other injectors which were tested gave a good range and a good maximum delivery but with peaks which were further back in the pressure range, in some cases as low as was indicated by curve C on the diagram. One particular injector used in large numbers and considered satisfactory for many years gave a surprising performance with a range between the maximum and the minimum of only 800 lb. and this was shown on curves D and E. In this, as in so many other things, it was possible to go on for many years with what one considered the very best instrument. One was so used to it that no questions were asked about it. Yet the moment the opportunity arose to make strictly comparable tests quite interesting results were achieved.

There were two points on which he would like to join issue with the Author. First of all, he had eulogised the old face plate type of injector, the type which was of the lifting variety. He himself had been brought up on a railway which had standardised that type of injector, and unless maintenance was very good indeed it was a very troublesome instrument. There had to be complete tightness of the suction pipe line, and one had to be very careful that the injector body itself did not become heated due to leakages. In the event of any of these occurring, a lot of trouble ensued, and he ventured to suggest that very few locomotive men would welcome the return of that type of injector. The possibility of overheating certainly lent some justification to the more modern trend of putting the injector into a cool part of the locomotive chassis.

Finally, with regard to the exhaust injector he supported the President. Properly applied, the exhaust injector was definitely worth while. In 1946 some tests were carried out to try to settle policy regarding the fitting of these injectors to engines on intermediate kinds of work. Tests were carried out on a relatively easy

line from Manchester to Southport with 2-6-4 tank engines with and without the exhaust injector, and figures previously obtained were confirmed, the coal saving being 10 per cent. and the water saving 8 per cent. At the opposite extreme other tests were carried out with stopping trains on a very severe route, namely from Manchester to Buxton. Under these conditions the saving was only of the order of 3 per cent. It was interesting to note that whereas on the easy run the exhaust injector was working for 77 per cent. of the running time and exhaust steam was being used for that percentage of the time, on the stopping train over the severe grades it was only used for 46 per cent. of the time on the average. Indeed, on the run down to Manchester it was only used for 22 per cent. of the time. Whereas one would obviously employ an exhaust injector without question on a continuous run, therefore, it was possible to calculate the kind of service below which it might not be justifiable to fit the instrument.

He would like to ask one question about the Gresham and Craven so-called feed heater, which was a form of clack box on the boiler top. He had never been able to understand clearly what was claimed for that device, because the steam which was drawn in to achieve the feed heating came from inside the boiler itself and he could not see that it represented very much advantage thermally as compared with dropping the water over some form of top feed tray.

Mr. H. Holcroft (M.) said that as one who had much experience with exhaust steam injectors he regretted their temporary fall into disfavour in late years. It was, therefore, very pleasing to hear from the President of the intention to reinstate them. The somewhat defeatist attitude towards these injectors had arisen, in his opinion, from the fact that they had become far too complicated. The move by their makers towards the fully automatic and very compact design of the H type injector was in the wrong direction, and for easy maintenance it would be preferable to revert to an arrangement following on the lines of the old B type, which was in two separate portions, and to cut out automatic controls because they increased the liability to failure. "Push-button" operation was realised at too heavy a price in first cost, maintenance and reliability.

It was more than ever necessary at the present time to avoid detention of engines in shed. If anything went wrong with an exhaust steam injector, it was a shop job; the engine had to be stopped, and it took two men the best part of a day to uncouple all the pipe connections and rods and lower down the heavy weight and then replace it by a spare injector. With a simple live steam injector, on the other hand, located in an accessible position behind the step plate, one man with a couple of spanners could quickly take out the whole set of cones and examine or replace them by another set, and without having to move the engine over a pit to do so. By this quick change, the engine would not lose a turn of duty, and that consideration weighed more against the exhaust injector than

anything else. If the design could be modified so that the sets of cones could be changed with the same facility as those of live steam injectors, without the need for breaking pipe connections and uncoupling control rods, and thus detaining the engine for so long in shed, it would be a move in the right direction.

One thing that struck him about the paper was the extraordinary complexity and variety of injectors which the Author had collected. Why should it be necessary to have so complicated an instrument, when a very simple make of under-footplate injector of the sliding or split cone type would meet all requirements ?

In Maunsell's day on the Southern Railway a special point had been made of the simplicity and reliability of injectors and their accessories. The injectors were located behind the footsteps to the cab where the cones could be got at without having to uncouple pipes to do so. There was only a lift-up handle on the front of the tender for the water valve and a pull-down handle on the manifold above the firebox for the steam. Two simple movements were all there was to it, and these could be made in the dark or when visibility in tunnels was nil, due to smoke and steam, as one knew exactly where to put one's hand on the two controls to give a mere pull or push to each.

The boiler clack was an indispensible accessory to the injector. The mushroom type valve with wings was liable to stick if the cage in which it worked had a slight coating of scale on the unused portion, which the vertical lift of the wings did not normally keep clean; should the valve for any reason manage to turn itself slightly, it got held on the roughened surface. On the other hand, giving the wings the very slightest twist caused the valve to spin, and that kept the valve cage clean, so that the valve did not stick. At the same time, when it seated, any scale or dirt trapped on the seating was flung off by the rotation, instead of being nipped between vertically moving surfaces.

He entirely disagreed with the Author about his views on the best positions of clacks and injectors. Mr. Cox had pointed out some of the objections to the combination type of injector above the footplate, and the speaker fully supported all that had been said on the subject. Another disadvantage was the noise created by the working of the injector in the cab. It added yet another noise which the enginemen had to put up with. Then again, there was the long internal delivery pipe through the boiler which had to be threaded between the firebox stays, and this was an obstruction to washing out. Such pipes were inclined to scale up internally, necessitating removal for cleaning.

With an outside delivery pipe and the clack boxes mounted on top of the barrel everything was accessible. The Author's objection to outside pipes, was the heat loss, but this was insignificant.

After some experience with them, he did not think the use of trays with top feed was of much advantage. One objection to them was that crusts of scale were liable to break off the trays and drop down amongst the nest of tubes, and perhaps start a block which

could only be broken up by the withdrawal of some boiler tubes. He considered that the best way of introducing water was to deliver it to clacks on top of the barrel, from which short internal delivery pipes diverted the feed to the sides of the barrel, clear of the tubes. These short pipes could be arranged to be easily detached for cleaning during periodical examinations.

Mr. W. G. F. Thorley (A.M.) said the Paper appeared to divide itself roughly into two parts. The first fifty-two pages gave the facts and the last page and a half the personal opinion of the Author regarding the relative merits of the live and exhaust steam injector. It was the last part which would make the most immediate appeal to motive power personnel.

Mr. Cox's remarks on the tests, he continued, were highly interesting. If these tests embraced exhaust injectors it would be most useful if, at the appropriate time, the results could be made widely known, and would be of the greatest encouragement to motive power personnel to continue in their endeavour to get the very best performance from the injector. He had just been told that coal at pithead was now 49/11½d. per ton, and that created a situation of sufficient gravity to make everyone do his best with these instruments if they were convinced of their value.

He noticed that in Kastner's Paper No. 396, read before the Institution in 1938 (Journal No. 147, Jan./Feb. 1939—Ed.), the merits of the exhaust injector, particularly as regards coal and water economy, were discussed at some length. After that discussion, however, the real value of the economies obtained by their use still remained somewhat in the air, and still did today despite the claims made in the manufacturer's handbook. Motive power people would be greatly encouraged if the real position were put before them.

The Author mentioned a device to indicate to the enginemen whether or not the injector was working. He would like to hear the Author's views on this tell-tale device. It did not seem to have been applied in this country to any extent, and it would be interesting to know why, because if one had to look over the side of the cab to see if the injector was working, the results were sometimes disastrous, and at the very least one might lose one's hat! Yet the indication received from an overflow pipe was very much appreciated by enginemen. Some time ago a number of engines had been transferred from one end of the country to the other. They were fitted with lifting injectors in which the overflow pipe was not visible. Before the enginemen would use them in their new environment, a long overflow pipe had to be fitted, the open end of which was visible from the footplate. It would be interesting to know whether these tell-tale devices were reliable. One read about them in trade publications, but the people who sang their virtues were usually the people who made them and not those who used them.

He could not concur with the Author in the latter's statement that the injector fitted on the boiler back plate was probably the most popular ever with enginemen. It may have been until some-

thing better was given to them to operate, and they are certainly not popular at the present day.

He said regarding top feeds that he had been for over five years at a shed which maintained some 200 engines, and, whilst there was a certain amount of tube pitting at this particular shed, he did not recollect during the whole of the five years a pitted tube occurring in a boiler fitted with the top feed arrangement. He gave this information for what it was worth, but it had always seemed to him to be a good point.

In conclusion, he congratulated the Author on his Paper. He must, he said, have spent many patient hours on research in reference libraries amidst that peculiar academic odour which is inseparable from such institutions. These studies had culminated in a splendid Paper which would undoubtedly be a standard reference work on the history of the injector for some time.

Mr. M. A. Crane (M.) said that one noticed on looking through the paper that in the last hundred years the injector had become more complicated, more difficult to operate, more difficult to repair and—dare he say ?—more expensive to buy. Was it really more efficient than the original invention ?

The question of top feed was somewhat divorced from the injector, and much could be said about where the water should be introduced. The Author had confined himself, for the most part, to the operation of the injector, although he had mentioned top feed in relation to position. It would be remembered that the Great Western Railway had used the ball type of clack to overcome the difficulty of scale, but he believed that they had afterwards employed the barrel shape, which was supposed to be an improvement on the spiral wing valve to which Mr. Holcroft had referred.

Perhaps the members would agree that what one was looking for in the injector was not so much its performance in delivering water into the boiler—presumably it did this with reasonable efficiency after a hundred years of development—but how it should be operated and repaired. With the changing times and with staffing difficulties in England and other countries, the injector must obviously be easy for the fireman to work. It must be accessible and visible. In this connection, he would like to ask the Author what progress had been made with a visual aid so that the fireman would be able to tell quickly that the injector was working properly ? One speaker had already mentioned the disadvantage of leaning out of the cab to observe the overflow pipe. A second difficulty was to locate the overflow pipe when the injector was moved into various positions on the engine frame. Could the fireman have something to tell him when it was working, and could he have an injector which needed the minimum amount of attention and care on his part to operate it. This would seem to be the fundamental issue rather than the finer points—the half-a-dozen cones to see one was getting that little bit of extra work or snatching that extra thermal economy from exhaust steam or live steam, and so on.

Mr. J. N. Gresham (M.) said he had been interested in the comments of one speaker on top feed with pitted tubes. A series of experiments had been carried out in America on an enormous number of boilers in a variety of conditions. The speaker's experience was amply confirmed. That was why his own company had brought out the queer type of top feed arrangement to which Mr. Cox had referred. No thermal efficiency was claimed for it at all. It was, however, claimed that certain salts came out of solution as the temperature increased and were deposited in the form of fine sludge rather than sticking on to the plates. Secondly, no cold water as cold water was put into the boiler. In that connection, he must take up Mr. Holcroft's point of the short delivery pipe fitting into the bottom of the boiler. One was putting relatively cold water into the very worst place one could find.

With all due deference to Mr. Cox's statement, he continued, he did not feel that it is fair to say all types of modern injectors were tried in the test to which he refers. So far as his request that he would like greater flexibility at the top end of the curve, there would be no difficulty in meeting this providing he was prepared to sacrifice something at the bottom end of the curve. The Injector is a flexible instrument, is designed to work over a large range of pressure and with a fairly wide range of temperature and, therefore, necessarily a compromise; any improvement in performance from a particular angle would of necessity re-act on other aspects of its performance.

Mr. T. Henry Turner, M.Sc. (M.) thought the question of top feed depended largely on whether the feed water was chemically treated. There was no doubt that the use of top feed had reduced pitting and general corrosion where the feed waters were not fully treated with alkali and tannin. He thought top feed was not so necessary where the boiler feed water was adequately treated before being fed to the boiler.

The efficiency of all the injectors the Author had described and illustrated could be and frequently was ruined by scale deposited on the injector components. In many parts of the world injector components were periodically cleaned in acid. It was worth noting, therefore, that if suitable alkaline chemical and tannin additions were made to the feed water before it reached the injector, there was no such trouble with scale and no need for acid cleaning.

This year he had watched the dismantling of a number of injectors from French locomotives in nine locomotive depots. He had seen no scale on any of them because the addition of tannin and alkalis to the locomotive feed waters had become a normal routine in France. These injectors were therefore fed with chemically treated water.

In such circumstances, top feed was not so necessary because pitting and corrosion would be inhibited by the daily control of alkalinity and tannin content of the feed water.

Mr. F. G. Clements (A.M.) said he would like to support the Author's objection to the exhaust injector. The modern tendency would appear to be to place the injector beneath the footplate and deliver externally through a top feed. Not the least of the claims for economy with the exhaust injector was feed water heating, and by putting the injector in that position and taking the pipe externally, one destroyed some of the values claimed for that injector.

Another point which struck him with regard to the layout was the difficulty of maintaining external feed pipe joints and the like. An injector mounted on the framing moved relatively to the boiler with the result that trouble from loose joints arises. He suggested this could be avoided if the injector were mounted on the firebox.

WRITTEN COMMUNICATIONS

Mr. J. Koffman (A.M.) wrote that the Author has gone to a very great deal of trouble to trace the development of the injector through the last 100 years and, as the result, presented a fascinating study of man's endeavour to harness Bernoulli's theorem in this particular field.

It may be mentioned that Daniel Bernoulli (1700-1782) belonged to the third generation of a remarkable family which in three generations produced eight outstanding mathematicians, who in turn produced a very considerable number of descendants who achieved distinction in science, literature and law. The theorem due to Daniel Bernoulli was published in his book " Hydrodynamica " (Strassburg 1738). It states that the total energy of a fluid is equal to the sum of the potential or actual head, the kinetic or velocity head and the pressure head, and since energy cannot be created or destroyed, the sum remains constant (neglecting losses). Since here we can neglect the potential head, an increase in the fluid velocity head means a reduction of pressure head, and vice versa. As for Giovanni Battista Venturi (1746-1822) he studied the recovery of pressure head in expanding tubes and explained in 1791 various difficulties in Bernoulli's theory. However, he had not put his conclusions to

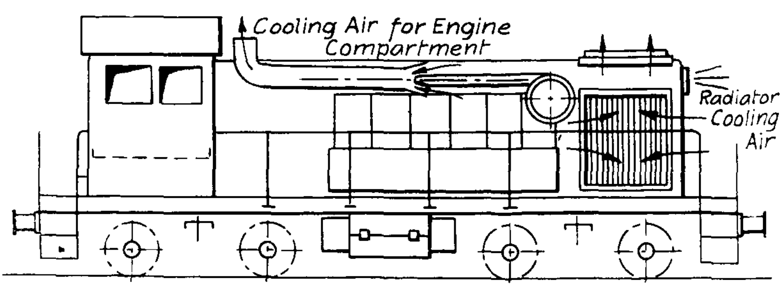


FIG. 36

EXHAUST EJECTOR FOR ENGINE COOLING

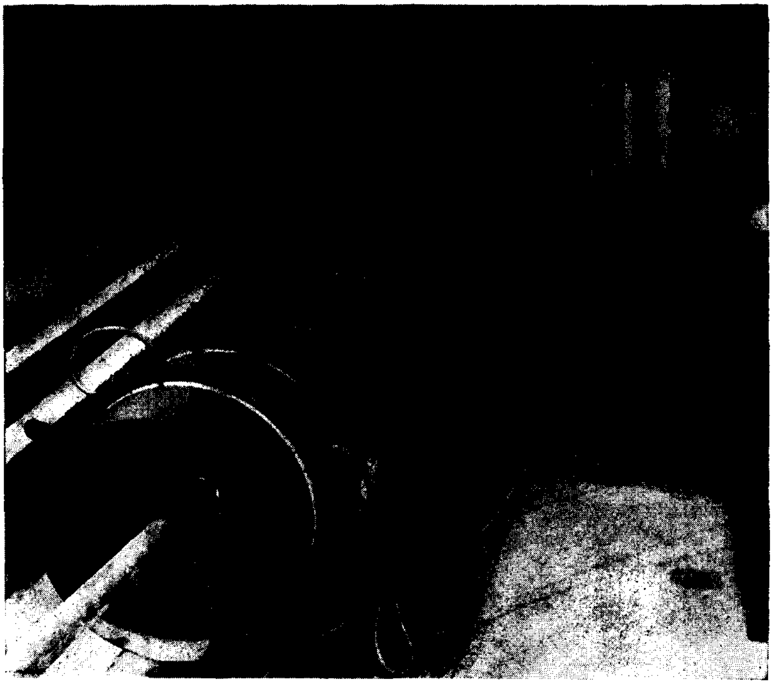


FIG. 37
EXHAUST EJECTOR TEST RIG

practical use. The Venturi meter was developed as a practical measuring device by Clements Herschel (American 1842-1930) in 1886. Thus the theoretical invention for the development of the injector was due to Bernoulli.

He felt that the value of this impressive collection of injector design data would be considerably enhanced if it would include performance data as well, particularly so far as modern representative units were concerned. Such data will be of value to all dealing with jet pumps (of which the injector was but a deviation), a subject at present of particular importance in many fields of engineering.

The writer was particularly interested in the application of the jet pump as a cooling system augmentor with diesel engine vehicles, and he had originally tried to approach the problem on the basis of injector or locomotive blast pipe experience. Considerations have, however, shown that a different approach was required and the theoretical basis of this, together with mean ejector proportions were dealt with by him elsewhere[1]. The idea underlying this development

[1] "Design of Exhaust Ejector," Diesel Railway Traction, London, August 1950, pp. 177-181, also Keenan, Neumann and Lustwerk, "An Investigation in Ejector Design by Analysis and Experiment," Journal of Applied Mechanics, New York, September 1950, pp. 299-310.

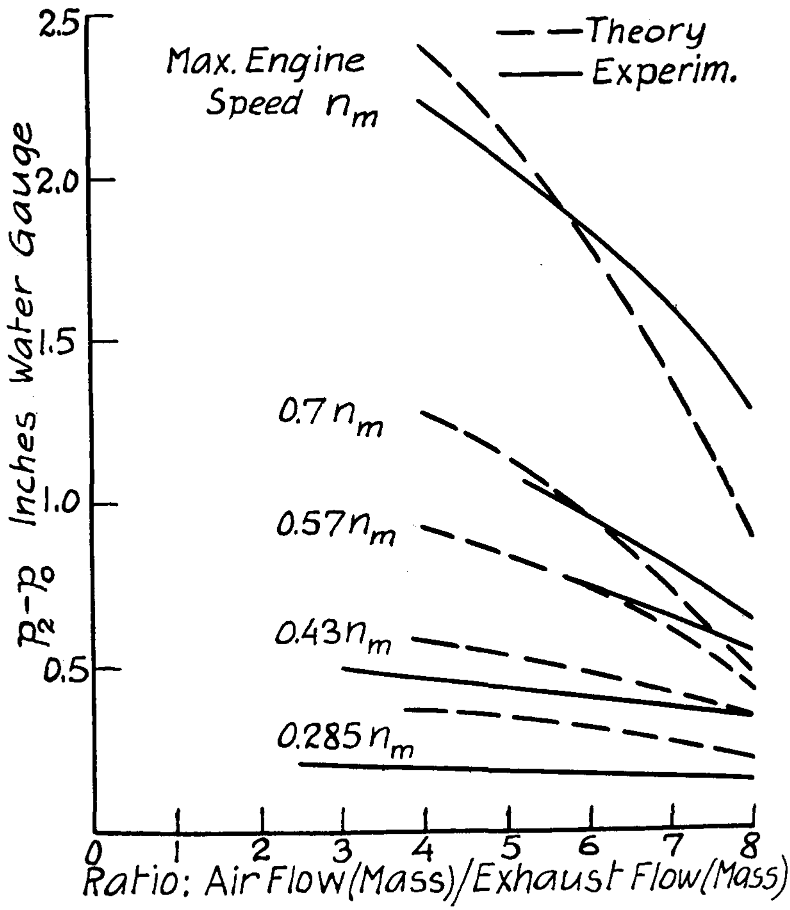
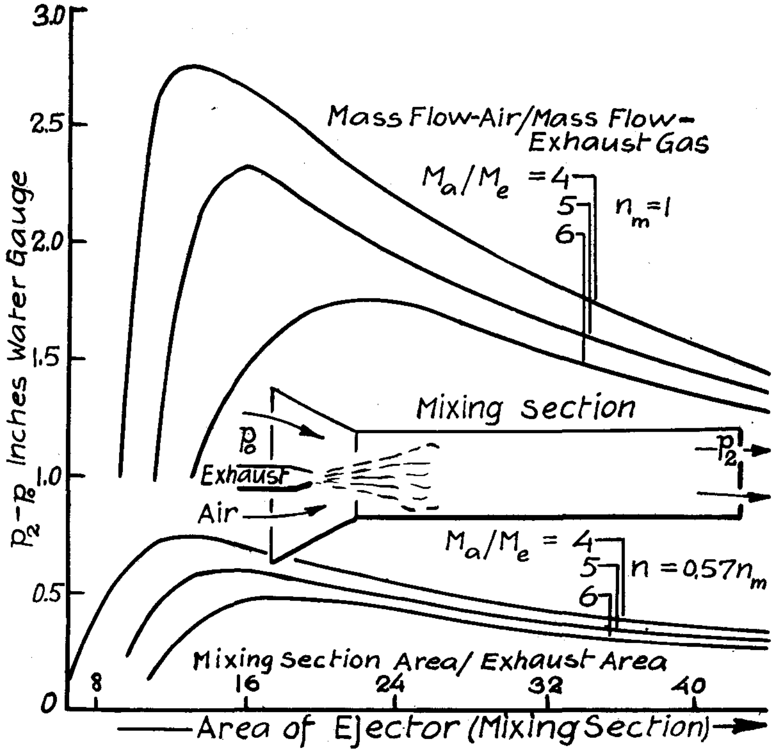


FIG. 38

TEST RESULTS

is based on the desire to utilise the energy contained in the exhaust gases to maintain an adequate air flow through the engine compartment and to use the fan to maintain the requisite air flow through the radiator only (Fig. 36). To substantiate the theoretically derived data, tests were carried out at the Fighting Vehicles Design Establishment of the Ministry of Supply with an engine coupled to a dynamometer, the exhaust actuating a jet pump arranged to enable the investigation of the effect of such variables as pressure losses and mixing tube length (Fig. 37). Because of the limitations usually imposed on length, the test ejector did not incorporate a diffuser. The main data are plotted in Figs. 38 and 39 and it will be noted



FIG, 39

EFFECT OF MIXING AREA ON PERFORMANCE

from the former that the agreement between theoretically predicted and actually measured performance is of a satisfactory order.

The jet pump may thus be considered as suitable for yet another application in the traction field.

Mr. G. T. Hart (A.M.) wrote that it would be very useful, particularly for the younger members, if the Author would explain as briefly as possible the fundamental principle of the injector explaining in particular why it is able to force water past the clack against boiler pressure. A similar explanation regarding the exhaust injector also would be appreciated.

AUTHOR'S REPLY

The Author in reply, said he noted the *President's* remarks regarding the exhaust steam injector, however the disadvantage of this type of injector was not in its being an exhaust steam injector but rather in its number of parts and their reaction on locomotive

availability and on Shed maintenance. This aspect being taken from the Running Shed angle and not from the economics of its efficiency as a feed water heater or a saver of fuel.

With reference to *Mr. Gresham's* remarks, the Author remarked that he had always been led to believe that the early Giffard injectors could lift water about 10 feet. The figures of 5 to 6 feet as quoted in the text were taken from the statement of Andrew Barclay in his description of his proposed improvements in 1864. With regard to the introduction of the divergent steam nozzle, which provided for the tendency of the steam jet to expand directionally, this was included in Gresham's patent of 1869, but according to Mr. Gresham's remarks, this type of steam nozzle came into use about five years later.

Mr. Cox was thanked by the Author for his remarks and demonstration with respect to the range of feed of injectors. An effort was usually made by an efficient Fireman to operate the injector at its minimum water valve opening with the steam valve at maximum opening to obtain the highest temperature of feed water.

Regarding the combination injector, its popularity does not appear to be so universal as he (the Author) had believed. The overheating of this type of injector was greatly overcome by the fitting of a pet cock at the lowest point of the feed pipe, so that any hot water accumulated in the feed pipe could be run off till the cooler water ran into the feed pipe. The Author again remarked that he took no exception to the exhaust steam injector as such, but to the time and attention the modern types required in the Running Shed. The exhaust injector was more sensitive to dirt in the cones than the ordinary injector, failure due to dirt, scale and pieces of coal lodged between the draught and vacuum cones require these cones to be extracted before injector could be blown through with steam, it was of little use, when stoppage occurred to take out only the discharge and combining cone in an attempt to clear any stoppage. Keeping the tender tank and sieves clean goes a long way to reduce exhaust injector failures in this category and it is advisable to have tanks cleaned more frequently on locomotives using the exhaust steam injector.

Mr. Gresham had already replied to the question arising about the feed heater as shown in Figure 20. When originally introduced it was claimed that this fitting fed water into the boiler at a temperature within 30°F of the steam temperature, also advantage was claimed from the fact that the salts held in suspension were thrown out of suspension with feed water over 300°F, and when deposited as sludge were easily removed from the boiler.

Mr. Holcroft's remarks regarding the exhaust steam injector were much appreciated. The compound injector was favourably commented on at one time both on the Continent and in America, but did not meet with much success in this country except in the case of the " B " type exhaust steam injector. In the first twenty years of this century one hardly knew there was an injector on the loco-

motives as far as maintenance was concerned, however the Author may have been fortunate in being in a part of the country where water troubles were unknown. In analysing the injector failures over a period of one year in one Region of the British Railways it was found that 80 per cent. of the failures were of exhaust injector types.

The general opinion at present appears to be in favour of top feed clack valves, but here again the discharge pipe lay-out and type of joints leave much to be desired as these generally require much attention at Running Sheds.

Mr. Thorley enquired about the efficiency of tell-tale devices; the only practical experience of this fitting recently available in this country was on the 2-8-0 U.S.A. " Austerity " locomotives where the apparatus shown in Fig. 23 (*b*) was used. These were not very reliable, as even with injector spilling water at the overflow, evidence was not always indicated at the swan neck outlet positioned on boiler back-plate about one foot above the footboards.

Mr. Crane asks if the modern injector is more efficient than the original invention. The Author's only experience of the early Giffard-Gresham Injector showed that they were somewhat temperamental and usually had some " trick " in starting. However, at that time the injectors would be at least 40 years old and with the intervening repairs and renewal of cones this opinion may not do justice to the early makers.

Regarding visual aid for Enginemen in telling quickly that the injector was working properly without spillage, at least on one Region recent design provides for electric bulbs at various points on the locomotive, one of which is placed above the injectors, which are both on the Fireman's side; this bulb throws a ray of light on the overflow pipe outlets. Otherwise " tell tales " have not been fitted to British locomotives, the Enginemen depending on aural and visual observation. On long non-stop night runs one cannot but have admiration for the Enginemen who can detect any irregularity in injector working long before this is obvious in the gauge glass; this seems to become second nature to them.

Mr. T. Henry Turner's remarks were very interesting in throwing light on the conditions under which top feed was desirable.

The remarks of *Mr. F. G. Clements* indicates that his experience runs in parallel with that of the Author's. The length of discharge pipes and position of joints leave much to be desired in the opinion of all who are responsible for locomotive maintenance.

Mr. J. Koffman's communication on the influence of eighteenth century scientists on injector development throws additional light on this subject and is a valuable contribution. It is of great interest that the use of the jet pump or injector principle has a field of application with oil engine traction, one of the main rivals to the steam engine.

The request of the *Secretary, Mr. G. T. Hart,* for an explanation —primarily for the benefit of the younger members—of the working of the injector and why it is able to force water past the clack valve against boiler pressure, is one which the Author was asked daily

when with the L.M.S. Instruction Train. Even after lengthy talks and demonstration one always felt that the class or individual under instruction was left not much the wiser, as to the so-called paradox action of the injector. To explain this paradoxical action without involving considerable mathematical science is the chief difficulty.

The " velocity " theory of the working of an injector, is that the high velocity of the steam entering the injector strikes and mingles with the column of water, the combined jet being carried along into the boiler; it then forces its way into the body of the water in the boiler which, though under the same pressure as the steam which operates the injector, is a passive body and cannot resist the velocity of the inflowing water.

It is argued, however, that if this theory is correct, injectors could be made with the steam and discharge cones of the same diameter, since the velocity would be there just the same to force the water into the boiler. Of course, an injector would not function under these conditions, the area of the steam cone must be considerably larger than the area of the discharge cone, the difference varying as the difference between the steam pressure and the pressure the injector forces against. The steam flowing into the steam cone is condensed by the water and the water temperature is raised. This mass of water forms a piston against which the steam acts and as the area of this part of the injector is greater than the area of the smallest diameter or throat of the discharge cone the water is forced into the boiler. When the steam supply to the injector is of low pressure, as with the exhaust steam injector, the area of the steam tube or tubes must be larger than with the ordinary injector, to overcome the pressure it must force against as compared with the lower initial pressure in the steam cones.

This is termed the " pressure " theory and can be further explained by the fact that injectors can be made to force against pressures four to five times the boiler pressure by having the steam cones of larger area analogous to a reciprocating steam pump requiring a larger steam cylinder to force against a higher steam pressure.

It is claimed that if the " velocity " theory was correct it would seem as though the pressure at the discharge cone would be practically independent of the area of the steam cone as long as the steam cone was as large as the discharge cone.

Perhaps both the " Velocity " and " Pressure " theories may be compromised in stating that the jet enters the boiler because the kinetic energy, which it possesses or its equivalent in pressure, is greater than that due to the head of the equivalent water column acting in the opposite direction i.e. on top of the boiler clack.

Injector manufacturers describe the action of the injector in a manner as follows—suppose the boiler pressure be 180 p.s.i., steam issuing from the boiler exerts pressure and expands eight to twenty-six times its original volume, depending whether it exhausts into the atmosphere or into a partial vacuum. In comparison, water under the same pressure would be discharged in a solid jet and without expansion. The velocities of discharge from a steam nozzle and a

water nozzle under 180 p.s.i. behave in different ways, the steam expands when issuing, reaching, at the end of the nozzle a velocity of 3,600 ft. per second, while the water, having no expansion, would have a velocity of barely 164 ft. per sec. or about 1/22 that of the steam. The same weight of steam discharging per second would therefore have considerably more energy for doing work than the water jet. If a steam or water jet comes in contact with a body in front of it the tendency is to drive the body forward, this force being equal to the weight of water or steam discharged by the jet in one second multiplied by its velocity per second. Suppose 1 lb. of both water and steam is discharged per second the momentum of the steam jet is 3,600 and the momentum of the water jet is 164. If the water jet discharged about 22 lb. per sec. its momentum would be the same as that of the steam 22 × 164 being approximately 3,600. The two jets are discharged under the same pressure, but the steam has 22 times the momentum of the water jet, it could, therefore, easily enter the boiler at 180 p.s.i. if we could reduce it to the size of the water nozzle. A difficulty arises here, a steam jet, say, 6 inches from the nozzle is much larger than at the opening and it would appear impossible to make it enter a smaller cone. Even at the narrowest part of the nozzle it is more than 16 times the larger in diameter than a water jet discharging the same weight per second, therefore, if the steam is changed to water without reducing its velocity, it would pass through a hole 1/16 the diameter of the steam nozzle at a velocity of 3,600 ft. per sec. The simplest way to reduce its size is to condense it and utilise its velocity. The water must be brought in contact with the steam without interfering with the direct line of discharge, the combining cone being used for this purpose. The effect of condensing the steam is to reduce the diameter of the jet, therefore this cone must be of a converging taper to lead the combined jet of water and condensed steam into the small end of the delivery cone.

The effect of the impact of the steam is to give to the water its momentum, so that a solid stream shall issue from the combining cone which contracts sufficiently in diameter to enter the smaller delivery cone. Should this delivery cone be connected to a vessel containing water under a pressure of 180 p.s.i. the water would issue in a solid jet with a velocity of 164 ft. per sec. Therefore, to enter the vessel the combined jet of water and steam must have a velocity of at least 164 ft. per sec. It will now be asked, what is the velocity of the combined jet at the discharge end of the delivery cone. If the steam nozzle discharges 1 lb. per sec. at 3,600 ft. per sec., the momentum will be 3,600 ft. lb. If the vacuum created by the condensation of the steam induces water into the combining cone at the rate of 10 lb. or 1 gallon of water per second at a velocity of 40 ft. per sec. its momentum will be 400 ft. lb. and that of the combined jet 4,000 ft. lb. the weight of the combined jet being 11 lb.

At the time of entering the delivery cone the velocity will be approximately 4,000/11 or 363 ft. per sec. however, owing to the steam and water not meeting in precisely the line of discharge there

is a loss of momentum and the velocity in the delivery cone will only be about 190 ft. per sec. We have now one mass of water leaving the delivery cone and travelling along the discharge pipe at about 190 ft. per sec. and another travelling down from the clack valve at 164 ft. per sec. the result being to the advantage of the water in the delivery pipe and this water would enter the boiler. Should the water used per pound of steam be reduced the combined jet would move along the cones faster, resulting in a larger margin in favour of the water in the discharge pipe. This theory may be feasible but one wonders how it would stand in modern times when the discharge enters the steam space of the boiler and it is in this respect that the " pressure " theory would seem to be desirable.

With reference to the exhaust steam injector, exhaust steam at atmospheric pressure has no velocity relative to the atmosphere, but if exhaust steam be allowed to flow into a vacuum it has a relative high velocity, and if issuing into a perfect vacuum 1 lb. of steam at atmospheric pressure would increase in volume from 26 to 172 cubic feet with a velocity of about 2,000 ft. per sec. When the exhaust steam is condensed in the injector a high vacuum is created the degree depending on the temperature of condensation.

The exhaust steam injector differs from the live steam injector in having the steam inlet nozzle of much larger size, this is necessary to provide for the large volume of exhaust steam which must be passed. Herein lies the fundamental principle of the operation of the injector, in that it is not dependent so much on the actual steam pressure, the main factor being the velocity of the steam. The exhaust injector uses about 8 lb. of water per pound of steam and the theoretical velocity of the combined jet is about 256 ft. per sec., but in practice only about 130 feet is realised due to internal losses as previously explained. This would not force the clack valve open in a boiler under 180 p.s.i. pressure where at least 164 ft. per sec. would be necessary.

A supplementary supply of live steam is therefore provided to produce an increase of velocity in the jet. The velocity of the combined jet is further increased by using the double jet system of steam supply. At the end of the exhaust injector draught tube in front of the exhaust steam cone a second supply of steam is admitted, which, flowing at a high velocity impinges on and is condensed by the combined jet, thereby increasing the velocity and energy of the jet.

MEETING IN DARLINGTON 1st NOVEMBER 1950

The Second Ordinary General Meeting of the Newcastle upon Tyne Centre was held at the Imperial Hotel, Darlington, on Wednesday 1st November 1950, the Chair being taken by Mr. R. W. Taylor in the absence of Mr. Hinds, the Chairman, who was indisposed.

The Minutes of the Meeting held on 4th October 1950 were read, approved, and signed as correct.

The Chairman then introduced Mr. T. H. Shields (M.) who read his Paper entitled " The Giffard Centenary—A Survey of Locomotive Injector Development."

This was followed by a discussion.

DISCUSSION

The **Chairman,** in opening the discussion, asked the Author the advantages obtained with the special arrangement the Western Region had fitted to the Class " H " Exhaust Injectors shown in the diagrams.

He asked the Author for his recommendations regarding modern high pressure locomotive delivery cone nozzles which appeared to wear very rapidly. He suggested that attention should be given to the methods of securing cones as these were frequently found to slacken back in service.

He asked what was maximum boiler pressure against which injectors had been used efficiently, and if there was a limiting factor.

Mr. Mc. Hugh (V.) said that the class F injector had all the advantages of any exhaust injector and he did not know that the class H or J had shown a greater saving.

Trouble with a class H or J injector was difficult to rectify. With the class F the only defect, apart from an occasional loose cone, was choking with ballast picked up by the water scoop, and that could be cleaned in a few minutes. All the developments in the exhaust injector seem to have been made to save the fireman getting off his seat and perhaps the Author could say if these later types gave a greater fuel saving.

He stated that when the F type was discontinued in favour of the H and J types, wear on the control piston was found to be excessive. This difficulty was never experienced with the F type.

Mr. Johnson (A.M.) asked if it was possible to regulate these injectors to any rate of feed in accordance with the rate of water consumption of the boiler.

Mr. Jarvis (M.) remarked that locomotives today are so economical, that when exhaust steam is used by the exhaust injector there may be difficulty in producing the necessary draught for proper combustion, hence there appears to be a limit to which the steam can be used after it has done its work in the cylinders. If this is so, boiler efficiency will suffer. The tendency may therefore be to use more live steam injectors, which are generally more trouble free than the exhaust type.

The type " H " exhaust injector on test gave a saving of 8 per cent. in fuel and 7 per cent. in water consumption compared with a live steam type. In the experiments the temperature at which water

was delivered to the boiler was 12 per cent. higher with the live steam injector but after modifications to the delivery and supplementary steam cones the temperature of the water delivered to the boiler was higher with the exhaust injector. It is very difficult to sum up exactly how much of the steam transferred from the blast pipe is put back into the boiler as water. There is a continuous flow from the boiler to injector and back into the boiler. Only the injector makers can say what these consumptions are.

He thought that whereas the exhaust injector is better for long continuous runs, the live steam injector is more suitable for engines which frequently stop and start.

Mr. W. D. Tattersall (A.M.) in proposing a vote of thanks stated they had had many papers on general subjects of design and only occasionally did they get such an interesting paper on a component of the locomotive. There was no doubt the Author had spent a good deal of time in research. On behalf of the meeting he thanked the Author for having devoted his time to read his Paper at Darlington.

AUTHOR'S REPLY

In reply to *Mr. Taylor,* the Author demonstrated by Fig. 28 the method of operation of the exhaust steam injector as used on the Western Region, where the change over from exhaust steam injector working or to exhaust steam injector working was manual and not automatic as with the " H " and " J " types of Exhaust Steam Injector, by this means a more dependable injector resulted.

Regarding delivery cone nozzles, modern injectors have usually renewable tips on the delivery cones and in some cases these are made of special steel, also on modern injectors loose cones are not so frequently experienced.

The maximum boiler pressure against which injectors can be used efficiently has been shown by test to be about 250 p.s.i., at this pressure the injector has reached the peak of efficiency but with an increase of steam pressure the delivery falls off gradually.

Mr. McHugh's remarks on the " F " type of exhaust steam injector seems to indicate that the exhaust injector can be too automatic so far as availability is concerned. The saving obtained by the " D " and " F " type injectors has been given as 10 per cent. in coal and three gallons of water per hour, due to the return of the heat of the exhaust steam to the boiler. For the modern " J " type the saving of 10 per cent. in coal and water over the ordinary live steam injector is claimed.

In reply to *Mr. Johnson* the Author stated that it was not difficult to regulate the injector to any rate of feed in accordance with the rate of water consumption of the boiler, especially on long non-stop runs where gradients were not too severe.

With regard to the remarks made by *Mr. Jarvis*, the exhaust steam used by the exhaust steam injector has not so great an effect on the blast as is at first imagined. The steam travelling along the exhaust injector steam pipe is generally only what is left in the blast pipe after the exhaust beat has occurred. The Author further stated that he had not observed any appreciable effect in the draught on the fire on locomotives that had the exhaust steam pipe to the injector blanked off for any reason, nor had he ever recalled enginemen stating that engines with this pipe disconnected steamed any better during the period engine worked without using exhaust steam for the injector. The small amount of exhaust steam passing along the exhaust injector steam pipe can be judged by the fact that, should this pipe fracture in traffic, no difficulty is experienced in engine completing its booked working (although the exhaust injector will be inoperative while regulator is open, unless the auxiliary steam from the steam chest is shut off) nor are the enginemen inconvenienced with exhaust steam affecting visibility unless in such instances as when the exhaust injector steam pipe is fractured close to the back of the smokebox.

MEETING IN GLASGOW 17th JANUARY 1951

The Sixth Ordinary General Meeting of the Scottish Centre was held at St. Enoch Hotel, Glasgow, on Wednesday 17th January 1951 at 7.30 p.m., the Chair being taken by Mr. C. D. Hanna.

The Minutes of the Meeting held on 13th December 1950 were read, approved, and signed as correct.

The Chairman then introduced Mr. T. H. Shields, who read his Paper, entitled " The Giffard Centenary—A Survey of Locomotive Injector Development."

This was followed by a discussion.

DISCUSSION

The **Chairman** opened the discussion with the remark that this Paper bore the same hall mark as all the Author's previous papers; diligent investigation and research; a strong appreciation of the value of historical facts and an exhaustive description of all the data he has gathered.

Much can be learned from the history of the mechanical development of any instrument or machine and it was certain that this Paper would provide a fertile source of reference, for it brought into focus the development which has taken place in the theory and manufacture of the injector during the last century.

It is an interesting historical fact that the family of Robinson must have had close on a hundred years association with the locomotive industry for, commencing with Mr. John Robinson who read the first paper on injectors before the Institution of Mechanical

Engineers in 1860 when he was a Director of Messrs. Sharp Stewart & Co., the connection was only broken in 1940 by the untimely death of Mr. C. H. Robinson, Director of The North British Locomotive Co., and an ex-Chairman of the Scottish Centre.

It was noted that the Author had incorporated all his contentious matter in his conclusion and from the Chairman's experience in the running shed he had not noted a great deal of trouble with either the lifting or non-lifting injector but there were numerous reports of leaking joints between combination injectors and their seatings on the back plate. These were always annoying joints to make owing firstly, to the small space between the flange and the body, and secondly, to the close proximity of other mountings. Another noticeable feature was that the steam and delivery pipes had a habit of moving inwards despite their being expanded and riveted over in the seating.

Mr. G. W. Phillips (M.) said that the first type of injector of which he had had experience was that commonly fitted until about 1895; it was non-automatic, and very troublesome as it flew off at bumps and jerks on the road.

The next injector fitted was the Gresham and Craven combination on the boiler front; this was very popular, but liable to overheat, and the water pipe had to be cooled down with damp cloths. Later, pet cocks were added at the bottom of the pipe to enable the heated water to be run off. The standing instruction for injector working was that water should be turned on before steam, and the latter shut off first—but with the Gresham and Craven combination injector, it was more satisfactory to shut off the water first, and the steam immediately afterwards. The water pipe was thereby kept full of cold water ready for the next time it was required.

There were two schools of thought regarding the working of injectors—one would supply sufficient feed with a quarter of a turn of steam (which is the speaker's practice) and the other school which turned on full steam, or four times as much. The latter point of view, of course, was that this put hotter water into the boiler.

The next important type he had met had been the Davis and Metcalfe exhaust injector, type D—fitted in 1909 or 1910 on the first G.N.R. Atlantics to be built with superheated boilers (Nos. 1452-1461). The makers claimed that the exhaust steam portion would deliver water at a pressure of 120 lb./sq. in. He thought at the time that if the boiler pressure were reduced below that, it might be possible to feed *with exhaust steam only*. He found that this was possible by a trial on a part of the road where the running was easy with the steam below 120 lb., the supplementary steam shut off, the engine actually ran with exhaust steam only for a number of miles.

Mr. Phillips later added that he had never been able to get the exhaust steam D type injector to carry on at much below 150 beats a minute, when the auxiliary steam had to be turned on. He confirmed that often there was little or no pressure in the exhaust

steam used, as this injector operated satisfactorily when the engine was working easily.

Mr. A. Hood (M.) made reference to the number of injectors used. We were now using two for the class 4, one live steam and one exhaust for class 5 and upwards, but some Colonial railways use three live steam injectors. The Crown Agents for the Colonies were calling for two live steam on the left and one on the right. The boiler was not tremendously large and he felt it would work satisfactorily with one.

Mr. B. C. Bean (M.) thought that maintenance was the reason for fitting three injectors to certain locomotives for Colonial railways. He did not know what the arrangement Mr. Hood mentioned was like as he had not yet examined it, but thought the reason for fitting three injectors was possibly to have at least one for a stand-by.

Mr. W. Robertson (V.) said that in view of the prevalence of casualties from injector trouble, there was something to be said for three injectors. He asked if the third injector could not be adjusted to work at a lower steam pressure. In these days coal was often of poor quality leading to trouble in maintaining steam. If the third injector could be worked at, say, 150 lb. per sq. in., casualties might be avoided.

Mr. A. C. Smith (M.) said that the point raised by Mr. Hood concerning engines fitted with three injectors brought to mind a class of 0-6-2 tank engines operating under the jurisdiction of the Calcutta Port Commissioners. These engines were fitted with two hot water injectors and a duplex pump. It is understood that the reason for this is that in the hot weather the locomotive tanks become too hot for ordinary cold water cones to pick up. The pump is fitted because each year, about March to July, there is an excessive amount of salt in the feed water and the crystallisation of this gives injector trouble.

Mr. P. Fraser (V.) remarked that on the old Drummond injector illustrated there was a clack valve and steam blew from the overflow pipe. The same happened with the Gresham & Craven combination injector, the steam coming in gusts and usually with spurts of water. It was particularly noticeable in the shed with the old Drummond because it was noisy.

He asked why the steam blow did not come continuously.

Mr. R. P. Critchley (M.), moving a vote of thanks to the Author said he thought a paper could be written on "why injectors fail to operate when in service."

The crux of the question, in his opinion, was adequate maintenance. Injectors should be tested every day in order to prevent scale forming on clack valves, cones, etc. Injector cones were not renewed frequently enough and although they appeared to be satisfactory on visual examination they were, however, found to be defective when checked against master gauges.

By strict attention to examinations and renewal of worn parts there should be no necessity to have three injectors on any locomotive.

He congratulated the Author on his very comprehensive paper and on behalf of the members thanked him for the trouble he had taken on this occasion.

AUTHOR'S REPLY

The **Author** in reply to the *Chairman* regarding the injectors made by Andrew Barclay & Co. said that this firm still made the "Caledonian" injector, but he did not know their method for automatic working as he had never seen this type dismantled. Regarding the small space between the combination injector and the boiler back plate this had really been altered to give more clearance for fitting the nuts. Before the amalgamation of railways it was common practice to fit a Gresham & Craven combination injector on the fireman's side of the footplate and a Davies & Metcalfe type on the driver's side, but the former type was more favourable. The furring up of internal delivery pipes he had seen, but little difficulty was experienced with this trouble on locomotives in Scotland. He maintained that among the enginemen on the Caledonian Railway the combination injector was very popular, and to overcome the defect of the injector becoming overheated a small pet cock was placed at the lowest point of the feed pipe to allow for running off the hot water accumulated in the pipe; of course this could only be accomplished when the locomotive was stationary.

In reply to *Mr. Phillips'* reference to the early Giffard injector, the Author said these had been fitted to Stirling's 0-6-0 locomotives (among others) on the Glasgow & South Western Railway, and placed on the gangway at the side of the boiler. Latterly they were used on shop boilers at Kilmarnock, and one could look into these injectors while they were working. These injectors were very temperamental and irregular in action, especially when not operated by the regular enginemen.

In regard to the working of the combination injector, or in fact any injector, it is recommended to use maximum steam with minimum water, so long as this was sufficient to maintain the water level in the boiler. This was somewhat analogous to the method employed by drivers in the handling of the locomotive—some worked with full regulator and some with half—but with the injector it is maintained that maximum steam and minimum water is essential for high temperature feed.

The "D" exhaust steam injector with its additional combining tube, received an impetus from a secondary jet of exhaust steam. By this means with exhaust steam alone, it was claimed, a pressure of about 120 p.s.i. was obtained. The exhaust steam injector is designed to allow the exhaust steam to expand into a high degree of vacuum and attains a velocity of about 2,000 feet per second, and it is this high velocity that may have, under favourable

conditions, enabled the exhaust steam injector to deliver feed water against the high boiler pressure, as experienced by Mr. Phillips, but from the earliest days of exhaust steam injectors these were useless without the supply of supplementary steam.

Answering *Mr. Hood's* point on the third injector, the Author said he thought it might be a question of bad water being taken into consideration, but otherwise he did not see how three injectors were required. The exhaust steam injector had still to be fitted on all engines of class 5 and greater, it being maintained that they are worth while on locomotives where continuous working predominates.

Answering *Mr. Smith,* he stated that with two injectors on the locomotive, they both should be working efficiently, if one failed the other should maintain the boiler. Both injectors should be tested before leaving the shed. Normally enginemen carry on with one faulty injector but there have been cases, however, where this has led to failure, usually through enginemen maintaining that one injector would not keep up the water level in the boiler.

On *Mr. Fraser's* comments, the Author said he was only too well aware of the point raised regarding the fluctuating roar from Drummond injectors when the clack valve was leaking—why, he did not know, unless it was caused by condensation in the discharge pipe causing steam and water to issue alternately from the overflow pipe.

The Author thanked the members for their vote of thanks and said the work involved in the preparation of the Paper had been worthwhile.

MEETING IN LONDON 16th NOVEMBER 1950

The Third Ordinary General Meeting of the Session 1950-51 was held at the Institution of Mechanical Engineers, Storey's Gate, London, on Thursday 16th November 1950 at 5.30 p.m., Mr. R. A. Riddles, C.B.E., M.I.Mech.E., President, occupying the chair.

The Minutes of the previous Meeting were read by the Secretary, and were confirmed and signed as correct.

The following applicants for membership were elected:

MEMBERS

ARMSTRONG, WILLIAM HAROLD, Assistant to C.M.E., New South Wales Government Railways, Redfern, New South Wales.

RICHARDSON, RAYMOND, Designing Engineer, Department of Railways, Sydney, New South Wales.

ASSOCIATE MEMBERS

ATHAVALE, SADASHIVA LAXMAN, Works Manager, Scindia State Railway, Gwalior, India.

ATKINSON, VERNON, Technical Assistant, C.M.E.'s Department, British Railways, L.M. Region, Derby.

BURNS, ROBERT ALFRED, Assistant Locomotive Superintendent, Nigerian Railways, Ebutte Metta.

FARMER, BILLY CABLE, Assistant Mechanical Engineer, E.A.R. & H., Nairobi, Kenya.

WALKER, HAROLD, Carriage & Wagon Works Manager, British Railways, N.E. Region, Newcastle-on-Tyne.

ASSOCIATE

BATE, REX, General Sales Manager, Brush Electrical Engineering Co. Ltd., Loughborough, Leics.

GRADUATES

BAKER, PETER, Junior Draughtsman, British Railways, L.M. Region, Derby.

BATY, JOHN NIGEL, Engineering Student, Rail Traction Department, Brush Electrical Engineering Co. Ltd., Loughborough, Leics.

MACMILLAN, NIGEL STUART CAMERON, Apprentice, North British Locomotive Co. Ltd., Glasgow.

RICH, FREDERICK, Apprentice, British Railways, Locomotive Works, Brighton, Sussex.

WARREN, JOHN MICHAEL DUNN, Apprentice, North British Locomotive Co., Glasgow.

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER

BRYANT, RAYMOND ALFRED ARTHUR, Assistant Engineer, Department of Railways, Sydney, New South Wales.